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STUDY
ON THE ESTABLISHMENT OF LABORATORIES
FOR ALUMINIUM SEMI-FABRICATED PRODUCTS*

prepared by

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1. INTRODUCTION

In the past two decades the geographic structure of aluminium industry has undergone radical changes with new bauxite mines opening in Australia and Africa, the building of alumina plants in many of the producing countries, and, most recently, with the construction of (and plans for) new smelters to provide vertically integrated domestic industries in the bauxite producing countries.

Primary aluminium is the second most energy-intensive major metal after magnesium in terms of unit energy values (Btus required to produce a tonne of metal), although it is considerably less energy-intensive than a number of minor metals. This is another reason for changing the geographic structure of the aluminium industry.

Recent studies have indicated that there has been a good correlation between changes in the level of GNP and metal consumption in the past. In low-income and medium income countries the rate of growth of consumption of most metals increases at an accelerating rate as incomes rise; once a country reaches a relatively high level of GNP the rate of growth of metal demand begins to decline (1,2).

The demand for energy bauxite and alumina is a function of the demand for metal to produce semi fabricated and final products. All is "hand by hand" with the demand for development.

UNIDO is often approached for information and supply of documents related to the development of the metallurgical industry in general and the aluminium industry in particular and a number of studies are already available with the organization (Ref. 1 to 4).

The most recent UNIDO study in the aluminium industry field is the one prepared by a team of consultants under the leadership of Dr. Domony, who have elaborated Guidelines for Processing Aluminium Semi-Fabricated Products (5).

The aim of this paper was to prepare a useful complementary document to the one done by Dr. Domony. The objective of the paper is to familiarize the reader with trends in the establishment of modern laboratories for aluminium semi-fabricated products, with special emphasis on services in developing countries. It suggests some solutions to serve various compositions of possible aluminium semi-fabricating plants.

Of course, the present paper may not embrace all details of laboratory in their entirity; it is actually designed (1) to reduce, as far as possible, time and cost involved in the preparatory stages of projects envisaged, (2) to present an exercise in response to which useful observations and new ideas are always welcome.

2. SEMI-MANUFACTURING PROCESSES AND PRODUCTS

2.1 General information of aluminium and aluminium production

The production of primary aluminium is essentially a three-stage process - mining of bauxite, refining of bauxite to alumina, and the smelting of alumina to produce primary aluminium metal. Production of secondary aluminium by-passes the first two stages of the cycle. These stages are shown in simplified form on fig. 1.

The beginning of the modern aluminium industry was with the simultaneous development in the United States and France of an economic electrolytic method of producing aluminium metal and patenting the Bayer process to extract aluminium oxide from bauxite. In 1886 both C.M. Hall in America and P.L.T. Héroult in France discovered that fused cryolite - a double flouride of solium and aluminium - would act as a solvent for alumina, which could then be electrolytically decomposed. In 1888 Karl Bayer announced in Germany a hydrometallurgical process to extract alumina which involved caustic leaching of bauxite at elevated temperature and pressures, separation of the resulting solium aluminate solution, and selective precipitation.

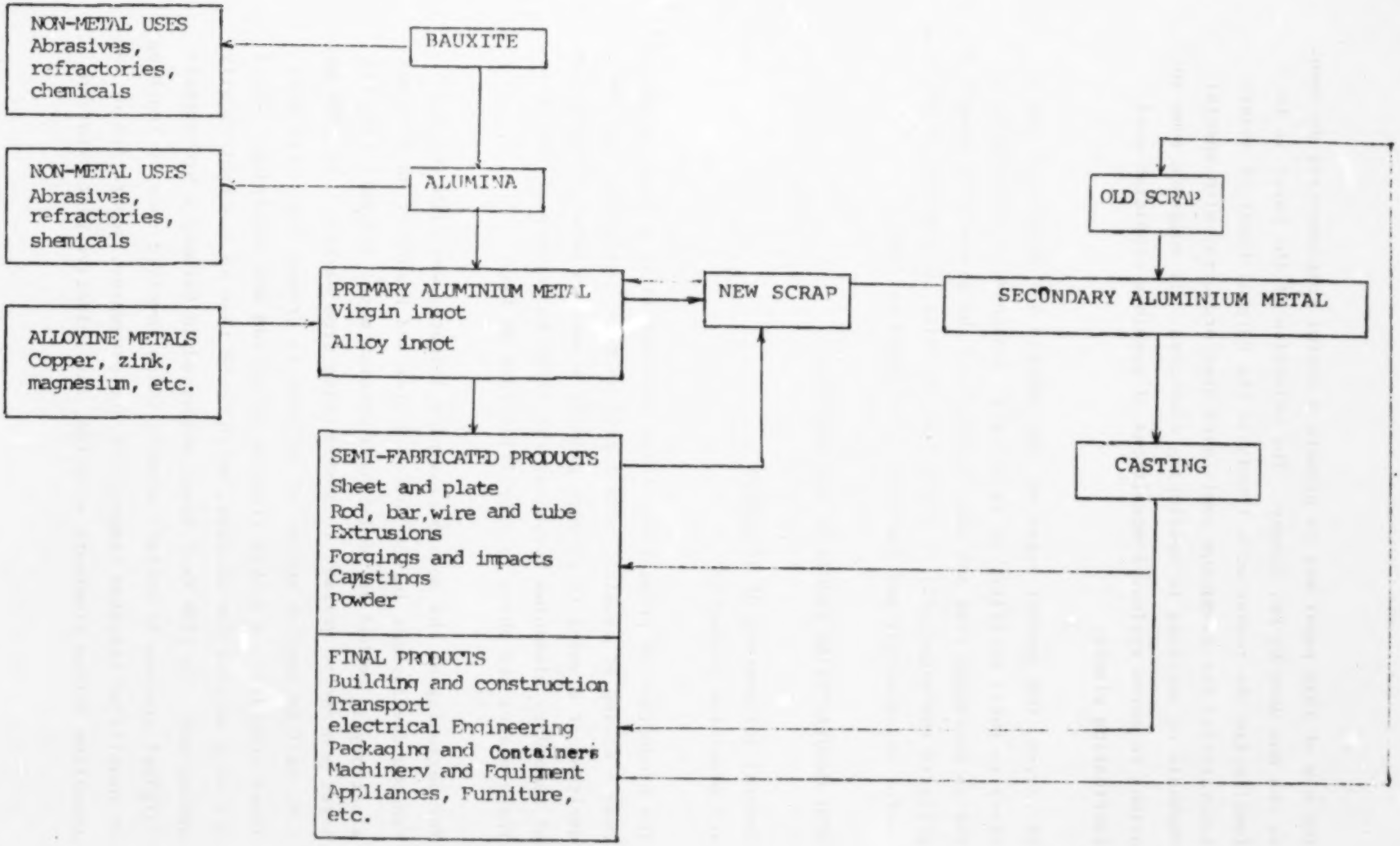


Fig. 1 SIMPLIFIED FLOW SHEET OF THE ALUMINIUM INDUSTRY

Although there have been many modifications and improvements of the Hall-Héroult and Bayer processes, almost all aluminium produced today is based on the work of these three.

2.2 General information on semi-manufactured aluminium

Semi-fabricated productions are usually classified into five categories: rolled products (foil, plate, sheet and coil, circles, slues and formed sheet); extruded products (shapes, rods and bars and tubes); wire and cable; forgings and castings. In the US it includes the five types of semis noted above plus powder; in Europe it excludes foil and castings; in Japan it includes only rolled and extruded products. The term "mill products" varies in use from country to country.

Although the technology of the production of semi-fabricated products is not dealt with in this study, the following brief summary, of the principal technological operations (and products of semi-manufacturing) is indicated in the tables 2-5 as background. Actually, five basic metallurgical processes are followed to get a previously mentioned five categories of semi-fabricated products.

Rolling: Rolling clock is first scalped to create a smooth surface; it is then heated and run through a hot rolling mill which reduces the thickness and increases the length to produce plate. Sheet is produced by further reduction by passing the plate through cold rolling mills (it may be annealed before the final cold rolling). After cold-rolling, heat treatable sheet and plate is heated and quenched. Next step is aging. Foil is produced by further reducing, annealing, followed again by more reducing. Hot rolling is avoided by the recent strip continuous casting process.

Extruding: Billet is heated and put into a extrusion press where it is forced through a die under very high pressure (in the case of seamless tube a hollow billet is often used). The resulting aluminium shape is then heat treated, stretched, contour rolled and aged.

Drawing: Drawing is used to produce rod, bar, wire and drawn tube. Rod and bar is produced by continuous casting and in line hot rolling, or from ingot which is first put through a blooming mill, then scalped, reheated and reduced in size by rolling. It is then drawn on a series of dies to a desired size, after which it is heat-treated, straightened and aged (drawn tube is first extruded and annealed). In the case of wire the same general process is followed, but the initial rolling reduces the ingot to a much smaller diameter than in the case of rod and bar.

Forging: Two basic processes are used. In the press process the metal, after heating, is squeezed into the shape of a die under continuous pressure from either a mechanical or a hydraulic press. In the hammer process the stock is heated and placed on a block holding a die which contains half of the product to be forged; a second die is used to strike the block and the process is continued until the metal conforms to the shape of the two dies.

Casting: Solidification process is used through the casting. Liquid aluminium is poured into a mould, allowed to harden, and may then be heat-treated. The methods used include continuous, semi-continuous and form casting (die casting, low pressure casting, centrifugal casting gravity casting and sand casting).

2.3 Structure of semi-manufactures

The main users of aluminium and aluminium alloys are the building construction, transport and the container and packaging industries. Semis are also widely used in electrical and mechanical engineering applications, for the manufacture of appliances (household and commercial), and in the manufacture of machinery and equipment. Miscellaneous users include powder, paste and flake consumers and the industries that use aluminium in sacrificial (metallurgical and chemical) applications. Table 1 indicates the wide variety of uses of aluminium semis (2).

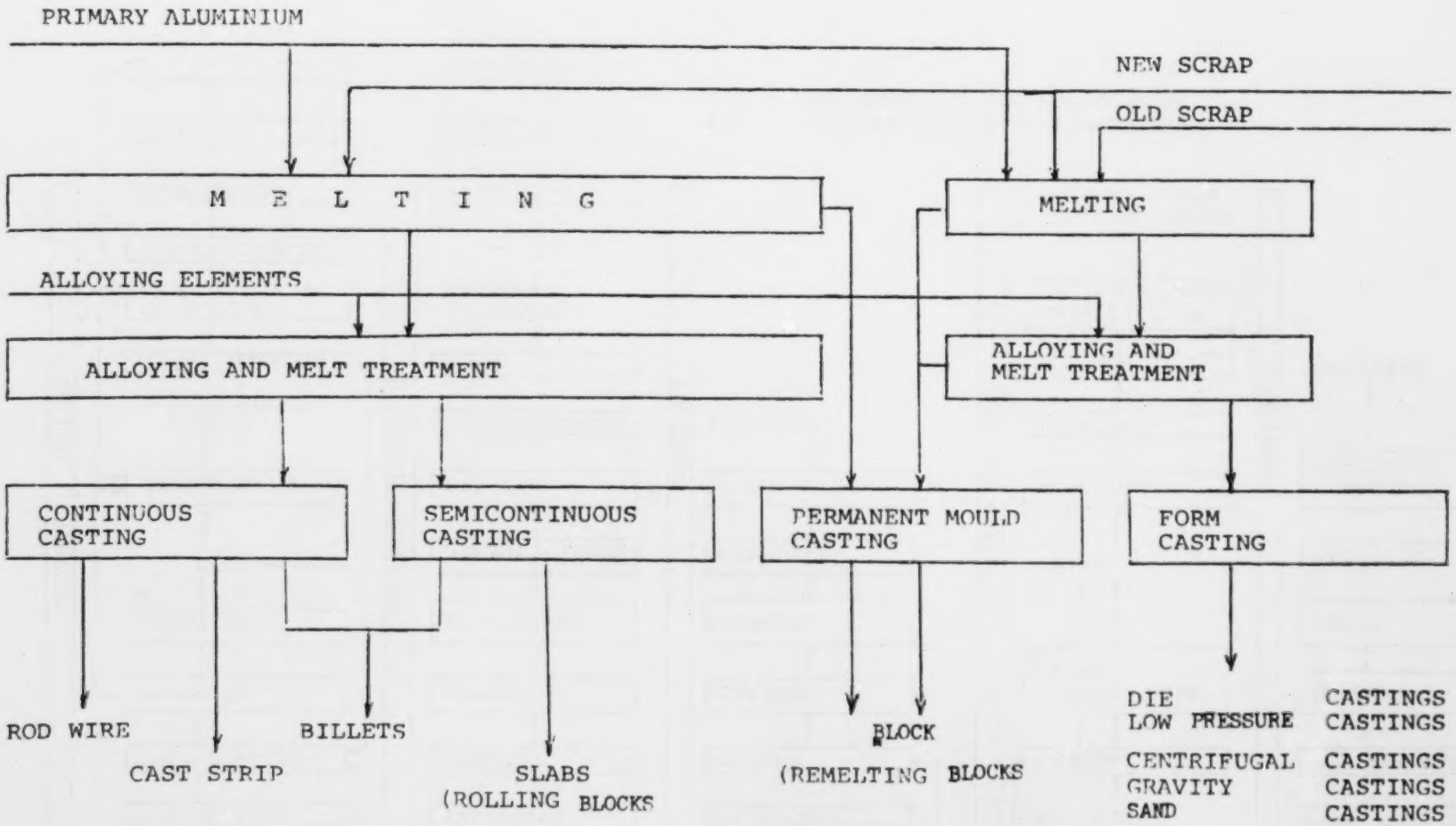


Fig. 2 PRINCIPAL TECHNOLOGICAL OPERATIONS AND PRODUCTS OF SEMI-MANUFACTURING (A)

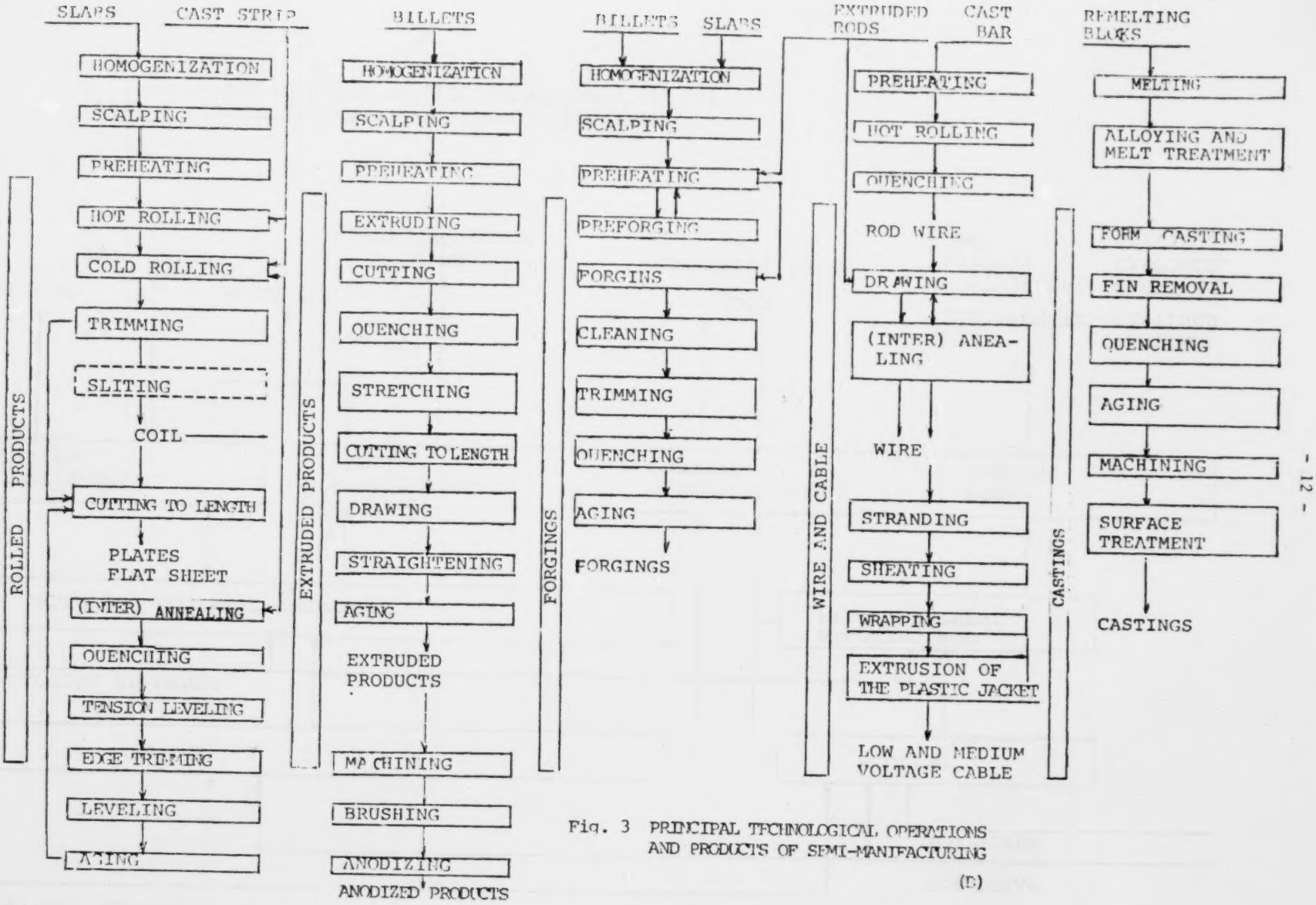


Fig. 3 PRINCIPAL TECHNOLOGICAL OPERATIONS AND PRODUCTS OF SEMI-MANIFACTURING

(B)

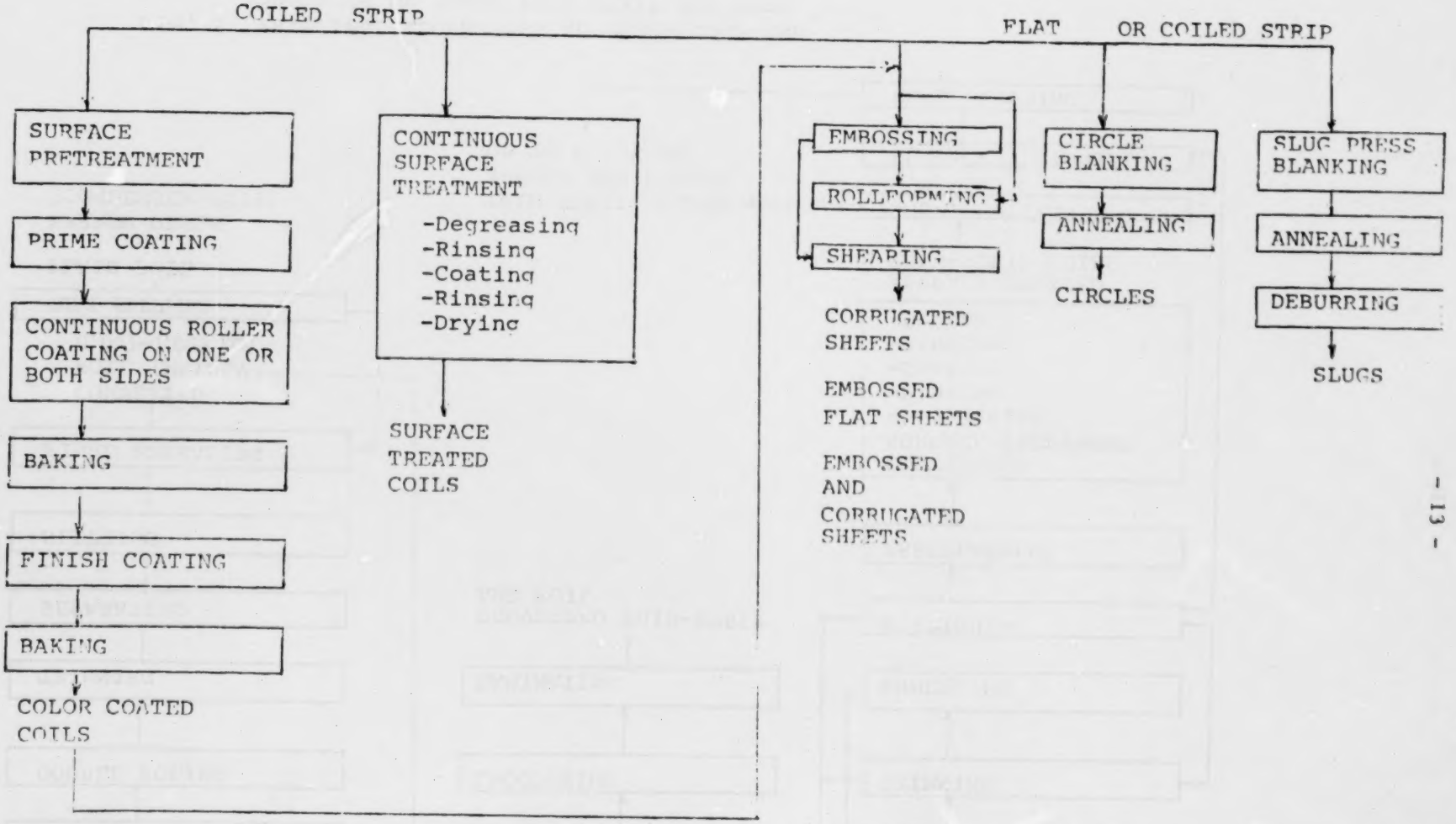


Fig. 4 PRINCIPAL STRIP - FINISHING OPERATIONS AND PRODUCTS

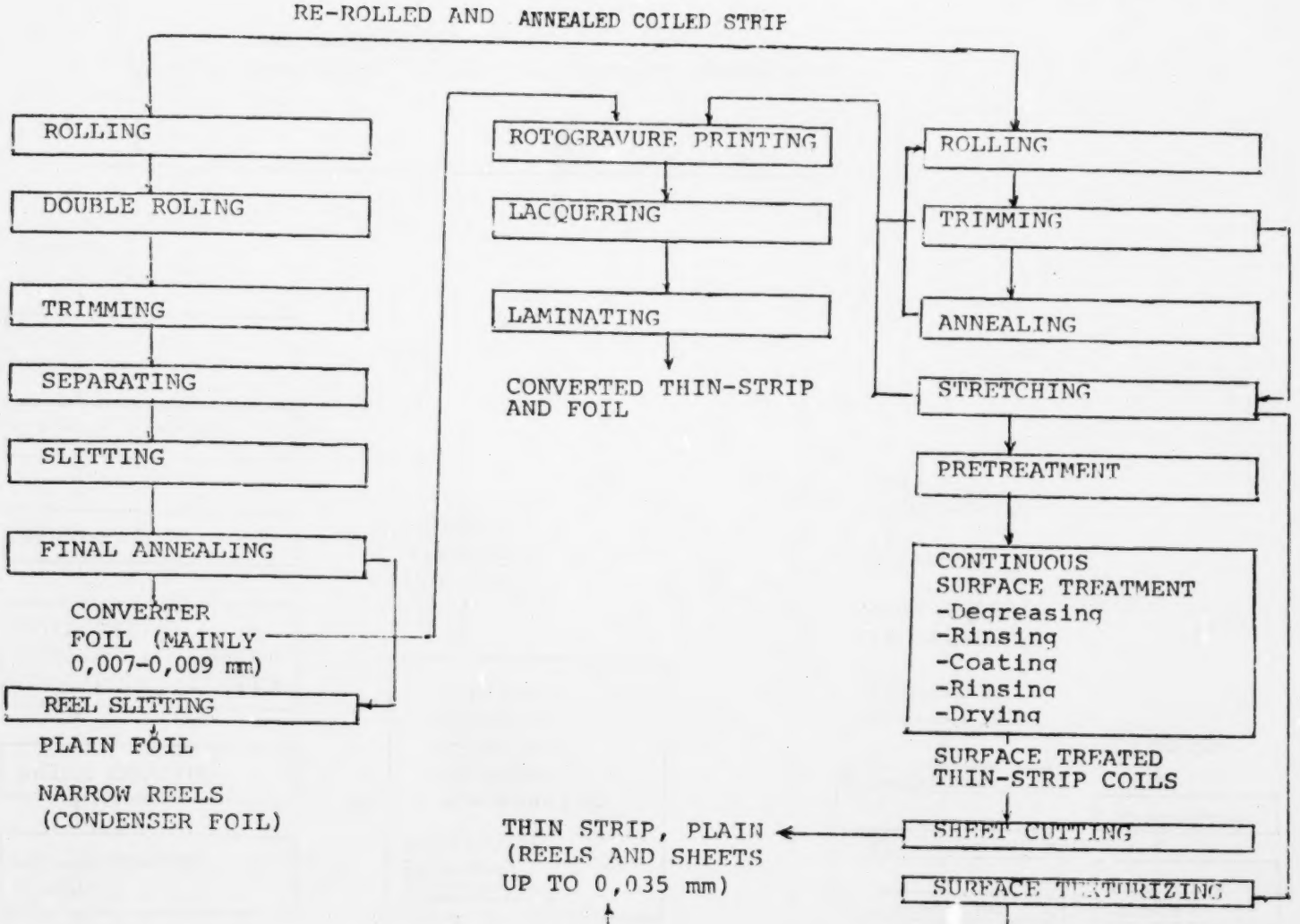


Fig. 5 PRINCIPAL TECHNOLOGICAL OPERATIONS AND PRODUCTS OF PLAIN THIN STRIP AND FOIL

Table 1 SOME TYPICAL USES OF ALUMINIUM SEMI-FABRICATED PRODUCTS

Industrial sector	Typical Applications
1	2
Building and construction	Wall cladding (exterior)
	Roofing
	Awnings
	Window frames and screens
	Door frames and doors
	Guttering and downpipes
	Installation and vapour barriers
	Mobile homes
	Stadium seating
	Road sign posts
	Light poles
	Pre-engineered structures
	Fencings
Transport	Boat bodies and ship cladding
	Railway coaches
	Helicopter rotors
	Marine propellers
	Aircraft cladding
	Metallic paints
	Automobiles: pistons, automatic transmissions, body trim, air conditioning, electrical systems brakes, steering, body sheet, engine blocks, crank cases, oil filters, "mag wheels", etc.
Electrical engineering	Wire and cable
	Electrical tubing
	Busbars
	Transformers
	Induction coils
	Telephone cables
	Computer components
	Electrical machines
	Lighting fixtures

1	2
Packaging and containers	Cans
	Caps and closures
	Foil (household and industrial)
	Metal ends and tabs for cans
	Semi rigid containers
	Aerosols
	Collapsible tubes
Mechanical engineering	Bearings
	Pomps
	Compressors
	Fan and blower components
	Hydraulic systems
	Lubrication systems
	Industrial tooling
	Heat exchange tubing
	Solar energy units
Appliances, consumer goods and furniture	Sewing machines
	Vacuum cleaners
	Refrigerators
	Freezers
	Airconditioners
	Washing machines and dryers
	Heating systems
	Electric irons
	Tent poles
	TV antennae
	Fishing rods
	Furniture frames
	Cooking utensils

1	2
Chemical and industrial machinery and equipment	Irrigation pipe and tube
	Agricultural machinery
	Materials handling equipment
	Mining equipment
	Textile machinery
	Chemical apparatus
	Business machines
	Instruments
Miscellaneous	Metallurgical applications
	Chemical applications
	Metallized paints
	Defence applications
	Sacrificial anodes to protect steel structure

2.4 Pattern and prospect of aluminium consumption in developed and developing countries

Table 2 shows the relative importance of the various types of semis in U.S.A., Western Europe, and Japan, although castings account for a considerable share of the total tonnage of semis produced (e.g., 20% of the total in the U.S.A.), data on their relative shares in Western Europe and Japan are not available. The differences in the pattern of production are due to the structures of aluminium finished product markets, for example, in Japan the largest consumer of semis is the building and construction industry (which uses extrusions), whereas in the U.S.A., although building and construction also take a significant share of semis (see Table 3).

The development of aluminium wire and cable for electricity transmission and distribution, new uses for foil and food packaging, and the two-piece aluminium beverage can are recent examples of important uses

developed for aluminium: new high-strength alloys have encouraged the use of aluminium in the transport and aerospace industries.

Table 4 shows intensity-of-use index for aluminium (1). The data indicate that the rate of increase of the index was very much slower in the U.S.A. and the Western European countries over the period 1951-1975 than in Japan, the Eastern Block countries, and the developing countries. In the future the rate of increase in the index in the U.S.A. and most of the more affluent Western European countries can be expected to continue to slow down.

On the other hand it can be expected that the intensity-of-use index in the rapidly growing developing countries and in some of the poorer Western European and Eastern European countries will increase in the next two decades as their level of GNP per capita increases - especially as they become more urbanized and industrialized. Fig 6 shows data on GNP and present per capita aluminium consumption in the less developed, Eastern Block countries and western industrialized countries. Comparison indicates the very large gap in aluminium consumption between the countries(1).

Table 2 PERCENTAGE SHARE OF TOTAL PRODUCTION OF VARIOUS TYPES OF ALUMINIUM SEMIS IN THE U.S., WESTERN EUROPE, AND JAPAN*

Product	% of total Semi Production		
	U.S.A.	Western Europe	Japan
Rolled products	65.8	54.7	34.1
Extrusions	23.4	33.0	57.4
Wire and cables	9.5	11.7	8.4
Forgings	1.3	0.6	0.1

* castings are excluded

Table 3 RELATIVE IMPORTANCE OF THE DIFFERENT APPLICATIONS OF SEMIS IN THE U.S., WESTERN EUROPE, AND JAPAN*

Application	% Share of Total Semis		
	U.S.A.	Western Europe	Japan**
Transportation	16.2	8.4	4.5
General engineering	5.7	5.5	9.1
Electrical engineering	12.4	13.1	16.7
Building and construction	26.9	23.7	48.4
Packaging	29.2	24.7	14.3
Home and office appliances	6.4	8.7	2.1
Miscellaneous	3.2	15.9	4.9

*castings are excluded

** data are for 1978

Table 4 INTENSITY OF USE OF PRIMARY ALUMINIUM* 1934-1975 (1)

Tonnes of primary aluminium consumed per billion US$ GDP (1971)

Countries or country groups	1934 - 1938	1951 - 1955	1956 - 1960	1961 - 1965	1966 - 1970	1971 - 1975
WESTERN DEVELOPED COUNTRIES:						
U.S.A.	493.0	2174.4	2387.9	3002.3	3647.3	3910.6
W.Europe	892.0	1564.9	1954.1	2283.6	2686.3	3056.3
Japan	534.0	866.4	1848.5	2258.2	3553.6	4863.3
Others	182.0	1286.9	1357.4	1803.4	2408.6	2876.2
DEVELOPING COUNTRIES:						
Africa	n.a.	36.7	56.6	163.2	346.2	559.2
Asia (excl. China)	n.a.	140.4	284.3	764.0	1332.0	1461.8
China	n.a.	43.5	558.5	1033.3	1477.7	1629.5
Latin America	n.a.	368.9	545.0	879.3	1207.1	1656.3
EASTERN BLOCK COUNTRIES:						
E.Europe	n.a.	875.8	1767.9	2246.7	3027.7	3646.7
USSR	316.0	1362.9	1691.3	2106.1	2205.6	2413.3
WORLD	n.a.	1478.1	1778.9	2239.3	2763.2	3092.8

* Data are for five year avareages

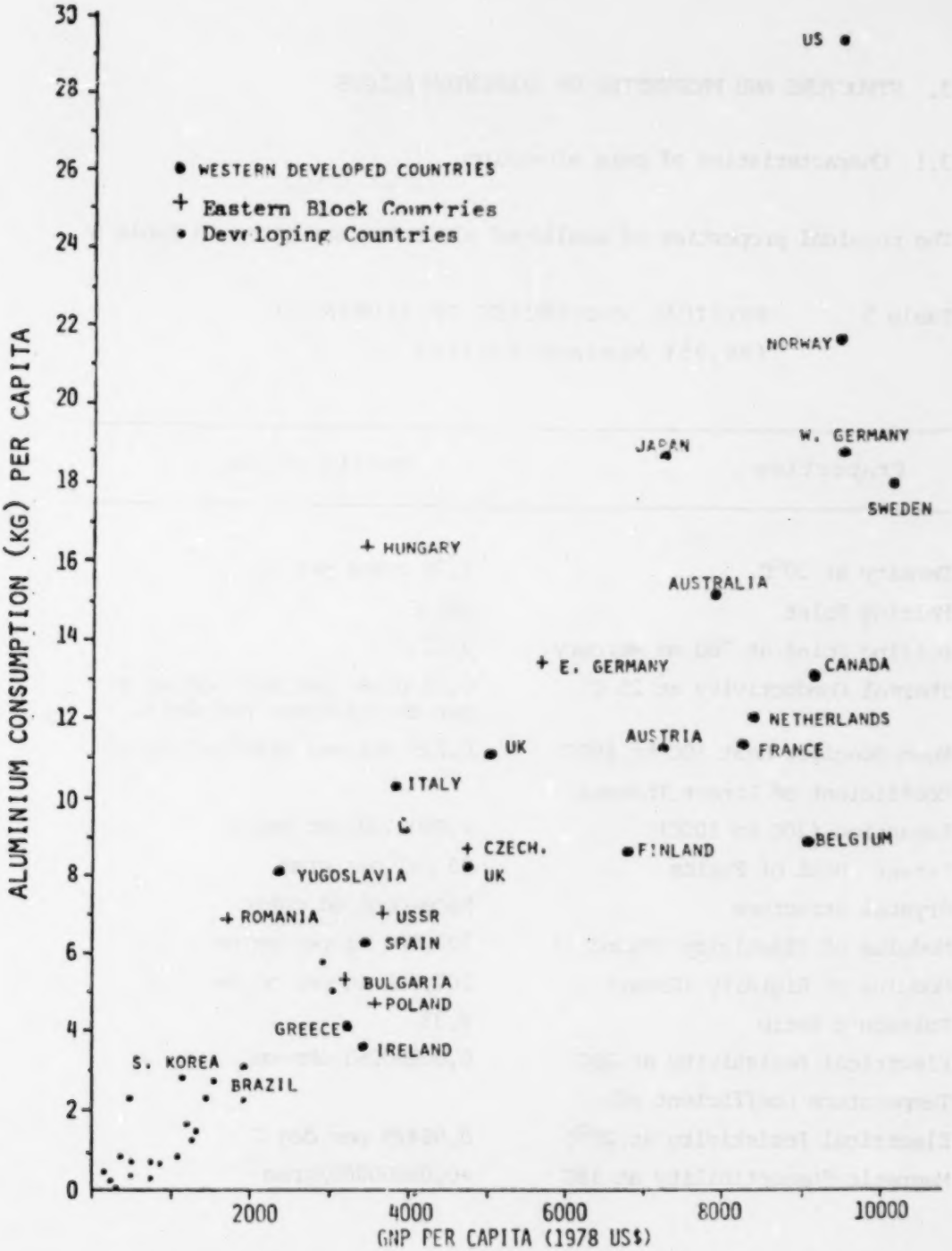


Fig. 6 ALUMINIUM CONSUMPTION AND GNP PER CAPITA

3. STRUCTURE AND PROPERTIES OF ALUMINIUM ALLOYS

3.1 Characteristics of pure aluminium

The physical properties of unalloyed aluminium are given in Table 5

Table 5 PHYSICAL PROPERTIES OF ALUMINIUM
(99,95% Minimum Purity)

Properties	Metric Units
Density at 20°C	2,70 grams per cc
Melting Point	660 C
Boiling Point at 760 mm Mercury	2327 C
Thermal Conductivity at 25 C	0,53 g cal per sec per sq cm per cm thickness per deg C
Mean Specific Heat (0C to 100C)	0,225 cal per gram per deg C
Coefficient of Linear Thermal Expansion (20C to 100C)	0,0000239 per deg C
Latent Heat of Fusion	93 cal per gram
Crystal Structure	Face-centred cubic
Modulus of Elasticity (Young's)	703,000 kg per sq cm
Modulus of Rigidity (Shear)	267,000 kg per sq cm
Poisson's Ratio	0,33
Electrical Resistivity at 20C	0,00000263 ohm-cm
Temperature Coefficient of Electrical Resistivity at 20°C	0,00429 per deg C
Magnetic Susceptibility at 18C	+0,00000065/gram

Following are the principal characteristics of aluminium.

Light - Aluminium is the lightest of all usual structural metals, except for magnesium. Because it weighs only about one-third as much as either copper or iron, aluminium sheet equal in weight and thickness to copper will cover about three times as much area.

Depending upon the section thickness necessary to meet the strength required by the application, an average of two to three times the number of products made of aluminium may be shipped and less transportation-fuel consumed.

Strong - Cold working increases the strength and hardness of aluminium and all of its alloys. Greatly increased strengths are further obtained by alloying aluminium with various combinations of manganese, silicon, copper, magnesium and zinc.

Some, but not all of the alloys can be additionally strengthened through heat treatments.

Some of the aluminium-based materials have the same or even better strength and hardness than structural steel.

Corrosion Resistance - Proper alloy selection and proper care can result in corrosion-free service for aluminium products in a wide range of applications on land, sea and in the air.

Conducts Electricity - Aluminium alloys are the most economical conductors of electricity available because they handle over twice as much current as does copper on a weight basis. High strength with high conductivity is obtained in the familiar large overland power transmission cables, which still conducts much more current than does copper on a weight-for-weight basis.

Conducts Heat - Heating and cooling applications both benefit from the fact that aluminium conducts heat three times as well as iron. Refrigerator evaporator coils, cooking utensils, engine components and heat exchangers of various types now are usually made of aluminium.

Reflects Radiant Energy - Aluminium is an excellent reflector of radiant energy. Polished surfaces are most efficient through the entire range of wavelengths, from ultra-violet through infra-red and the electromagnetic waves of radio and radar. Heater and lamp reflectors, roofing and siding sheet, and building insulation are principal applications of aluminium sheet and foil.

Non-Magnetic - For practical purposes, aluminium is non-magnetic, which makes it one of the few metals suitable for certain electrical and electronic shielding applications. It is also essentially non-sparking.

Non-Toxic - It has been used for cooking utensils and foil wraps for decades and is widely employed for industrial food-processing equipment.

3.2 Chemical composition of commercial aluminium and aluminium alloys

Primary aluminium is produced in a variety of grades, normally ranging from 99% to better than 99.9999%. Three different types, corresponding to different production methods, can be distinguished (7):

1. Commercially Pure Aluminium is the metal that comes from the reduction of alumina in the electrolytic cell and it is the bulk of the commercial production. It may contain up to 1% impurities and very seldom exceeds 99.9% purity.

2. Refined Aluminium is produced by electrorefining the commercially pure aluminium in the three layer cell. Its purity ranges from 99.9% to 99.99 + %.

3. Zone Refined Aluminium is produced by zone refining and, with proper

starting meterial and technique, can produce metal with less than one ppm impurities. This purity has been produced by zone refining metal electrodeposited from organic baths.

Secondary aluminium is produced by remelting fabrication scrap or obsolete equipment and is usually recovered in the form of alloys. Even when high-quality scrap such as electrical cable or bus bar is remelted, the "secondary pure aluminium" that result is less pure that the corresponding primary because of the unavoidable contamination with other materials.

Aluminium for electrical engineering (electrical conductors), E-Al (EC-Al) is the most important conductor material made from aluminium, specially treated in the foundry and sometimes specially alloyed. Within the scope of the permissible analysis the E-Al, which possess a minimal purity of 99.5% of aluminium considerable variations in the properties can be achieved. Basically, to achieve the desired properties as regards conductivity, each impurity must be kept especially low, since even at low concentrations, these have a significant effect on the electrical conductivity of the aluminium. According to certain research (8) these are especially the elements chromium, lithium, magnesium, niobium, titanium, vanadium and zirconium. In many standards this is partially recognised by restricting the sum of (Cr+Mn+Ti+V) to a maximum 0.03%.

Several analysis of various grades of primary metal are shown in Table 6.

Aluminium alloys are known through the related standard and standard-like designations used in various countries. Typical standard designations for aluminium and aluminium alloys are arranged systematically in the order of increasing number of letters or digits. Two are well known, Alphanumerical designations and Code and digit designations.

Alphanumerical designations give a direct indication of the nature and mass-percentage of the constituent elements. The Alphanumerical system is still in use because they convey considerable information about the composition, allowing a rough estimate to be made concerning the mechanical and chemical properties of the alloy. Their disadvantages consist in their non uniform length and in the irregular sequences of letters and digits, which are cumbersome for computerization. This designations are used by ISO (International Organization for Standardization) and some countries (Austria, Belgium, Canada, Switzerland, Germany-Federal Republic, Germany-Democratic Republic, France, Hungary, Portugal, Finland, USSR, Turkey and Yugoslavia, for example).

The International Registration Record is compiled by the Aluminium Association (AA), Washington, according to the 4-digit system. Besides all the composition limits for wrought aluminium alloys registered by companies or organizations in the United States, the Record also contains compositions supplied by organizations outside the U.S.A. that have an agreement with the AA of this effect. The following organizations (among others), in their respective countries, are parties to such an agreement: Aluminium-Zentrale (Federal Republic of Germany, Aluminium Federation Ltd. (Great Britain), Japan Light Metal Association (Japan), European Aluminium Association (EAA).

In the 4-digit system, the type of wrought alloy is indicated by the first digit as follows:

1XXX - Pure (unalloyed) aluminium
2XXX - AlCu and AlCuMg alloys
3XXX - AlMn and AlMnMg alloys (Mn is the main constituent)
4XXX - AlSi alloys
5XXX - AlMg and AlMgMn alloys (Mg is the main constituent)
6XXX - AlMgSi and AlSiMg alloys
7XXX - AlZnMg and AlZnMgCu alloys
8XXX - Other main alloying constituents
9XXX - Reserved

Table 6 RANGES OF ANALYSES FOR VARIOUS GRADES OF ALUMINIUM FOR THE VARIOUS ELEMENTS THE SIGN < INDICATES THAT THE ELEMENT IS BELOW THE LIMIT OF DETECTION OF THE ANALYTICAL METHOD USED

Element	Amount present (ppm)			
	Commercial 99.6-99.8	Electro-refined	Zone refined	Deposited from organic bath
1	2	3	4	5
Ag	0.1-1	0.001-0.1	0.001-<0.1	0.0005-0.002
As	0.008 - 0.5	0.006-0.3	0.00001-0.03	0.003-0.04
Au	0.001 - 0.5	0.0001-0,001	0.0001 -0.03	<0.00004-0.0001
B	0.1- 2	0.001 -0.1	<0.01	
Ba	0.1- 10	0.05 -2	0.001 - 0.03	0.006
Be	0.01-1	< 0.1		
Bi	<10	0.01 - 0.2	<0.003 - 0.1	< 0.1
Br	<0.1	<0.04	<0.01 - <0.02	
C	0.1-100	1 - 2	0.2-2	
Ca	0.1-50	0.1 - 0.2	0.02 - 2	<0.05 - 0.3
Cd	0.01-5	0.005-3	0.002-0.2	<0.005-0.01
Ce	0.01-1	0.01-0.3	<0.003-<0.01	
Cl	0.1-10	0.01-3	0.2-100	
Co	0.1-5	0.004-0.4	<0.0001-0.01	<0.01
Cr	2-50	0.01-0.4	0.01 - 0.5	0.004
Cs	< 0.01	0.000-0.01	0.0003-<0.1	<0.0003
Cu	5-100	0.4-5	0.0006-04	0.25-0.35
Dy	< 1	0.01-0.6	<0.004-<0.01	
Er		<0.01	<0.01	
Eu		<0.01	<0.0006-<0.001	
F	3-5	<0.1	<0.1	
Fe	400-2000	1.5-30	0.5-3	0.01-0.6
Ga	10-200	0.005-2	0.1-40	0.0001-0.05
Gd		0.01-0.04	<0.0001-<0.01	
Ge	< 1	< 0.03	<0.01-<0.03	0.66-0.13
Hf	<0.001	0.0004-0.07	0.0001-0.02	1.3
Hg	<0.001	0.0004-<0.07	0.00001-<0.01	<0.001
Ho		0.0005-0.01	0.0001-0.003	
I		<0.003	<0.003-<0.01	
In		<0.003-<0.1	<0.003-0.01	

1	2	3	4	5
Ir		< 0,005	< 0,005	
K	< 0,01	0,002-0,7	< 0,01-1	< 0,15-0,8
La	0,01-10	0,01-10	< 0,001-0,1	
Li	1-10	0,003-0,02		
Lu		0,002	≪ 0,0001-0,003	
Mg	5-50	1-20	0,1-0,0	
Mn	5-50	0,01-1	0,006-0,6	0,0008-0,03
Mo	0,1-1	0,005-0,4	0,0025-0,2	< 0,01
N	1-7	< 2-20	≪ 0,1-0,2	
Na	0,1-500	0,01-10	0,01-1	
Nb		< 0,01	< 0,01	3
Nd	0,1-1	0,1-0,2	< 0,01	
Ni	1-20	0,02-3	< 0,001-0,3	< 0,03
O	1-100	1-10	0,5	
Os		0,008	< 0,008	
P	1-30	0,1-10	0,04	
Pb	1-50	0,01-10	0,004-0,25	
Pd		< 0,001-< 0,01	< 0,001-< 0,01	
Pr	0,01-01	0,02-0,1	< 0,001-< 0,003	
Pt		0,5	< 0,5	
Pb	< 0,1	< 0,003-0,05	< 0,005-< 0,01	< 0,004-0,05
Re		< 0,005	< 0,005	
Rh		< 0,01	< 0,01	
Ru		0,03	0,03	
S	0,2-20	0,2-15	0,06-1,1	
Sb	0,01-2	0,02-1,5	0,00002-0,3	0,05-03
Sc	0,01-1	< 0,01-15	0,006-0,5	0,003-0,004
Se	< 0,1	0,003-< 0,02	< 0,0001-< 0,02	< 0,001
Si	200-100	1-30	0,1-0,8	
Sm	0,4	0,005-0,4	≪ 0,0001-0,03	
Sn	0,1-30	0,01-2	< 0,0001	
Sr	0,01-01	< 0,01-0,5	< 0,006-< 0,5	
Ta		< 0,1	< 0,01	< 0,006
Tb	0,1	0,003-0,1	≪ 0,001-0,003	
Te	0,01-0,1	0,006-< 0,05	< 0,0001-< 0,05	< 0,002-0,008

1	2	3	4	5
Th	<0.04	0.002-0.2	<0.00001-0.003	0.002
Ti	10-100	0.01-10	0.05-0.5	
Tl		<0.005-0.1	<0.005	
Tm		<0.003	<0.003-<0.01	
U		0.002-0.3	<0.00005-0.7	
V	5-100	<0.01-0.4	<0.03-0.5	
W	0.01-02	0.002-1	<0.0002-0.3	0.0002-0.001
Y	0.01-0.1	<0.01-0.1	<<0.001-<0.01	
Yb		<0.01-0.03	<0.001	
Zn	10-200	0.3-30	<0.001-2	0.06 - 0.17
Zr	10-40	0.01-2	<0.01-0.04	<0.04

The last two digits identify the aluminium alloy or indicate the aluminium purity. The second digit indicates modifications of the original alloy or impurity limits.

Elements which make up the major metal additions to produce aluminium casting alloys are generally similar to the groups of wrought alloys.

1XX.X - Pure (unalloyed) aluminium
2XX.X - AlCu alloys
3XX.X - AlSiCu, AlSiCuMg and AlSiMg alloys
4XX.X - AlSi alloys
5XX.X - AlMg alloys
6XX.X - Unused Series
7XX.X - AlZn
8XX.X - AlSn
9XX.X - Other main alloying constituents

A modification of the original alloy is indicated by a letter prefix before the numerical designation.

Castings are identified by a suffix zero (0) which is separated from the first three digits by a decimal point. Ingot, which has chemical composition limits almost identical to those assigned to castings, is identified by the fourth digit one or two (1 or 2) which is separated from the first three digits by a decimal point.

It is possible to meet related designations and compositions of aluminium products according to special applications: Low alloy Electrical Conductor Alloys, Aluminium alloys for automotive applications, Aluminium based bearing alloys, Powder metallurgy alloys, etc. (9).

The chemical composition of some selected aluminium alloys is given in the Table 7. The often used alloys and the alloys with the maximum content of alloying elements are listed.

3.3 Mechanical properties of aluminium and aluminium alloys

Commercially pure aluminium has a tensile strength of about 90 megapascals. Its usefulness as a structural material in this form is thus somewhat limited. By working the metal, as by cold rolling, its strength can be approximately doubled. Much larger increases in strength can be obtained by alloying aluminium. Like pure aluminium, the alloys are also made stronger by cold working. Some of the alloys are further strengthened and hardened by heat treatments so that today aluminium alloys having tensile strengths approaching 700 megapascals are available.

Figure 7 shows strain hardening curves for various popular non-heat-treatable alloys. The percent of reduction and corresponding tempers reshown at the bottom of the graph with the tensile strength and elongation along the left (11).

3.4 Electrical properties of aluminium and aluminium alloys

The most important conductor material made from aluminium is undoubtedly E-Al - specially alloyed and specially treated in the foundry - which is used in the manufacture of conductors. This material has by far the greatest significance in the applications of aluminium in electrical engineering. E-Al has its analysis, as well as its mechanical and physical properties, defined in international standards. However, the

Table 7

THE CHEMICAL COMPOSITION OF THE MAXIMUM CONTENT OF BASIC ALLOYING ELEMENTS AND THE MOSTLY USED ALUMINIUM ALLOYS (10)

ALLOY DESIGNATION Int. Reg.Rec.	Si	Fe	Cu	Mn	Mg	Gr	Ni	Zn	Sn	Ti	Notice
WROUGTH ALLOYS											
1100	0.95 Si + Fe		0.05-0.20	0.05	-	-	-	0.10	-	-	
2024	0.50	0.50	3.8-4.9	0.3-0.9	1.2-1.8	0.10	-	0.25	-	-	-
2419	0.15	0.18	5.8-6.8	0.2-0.4	0.02	-	-	0.10	-	0.02-0.1	0.1-0.25Zr
3009	1.0-1.8	0.7	0.10	1.2-1.8	0.01	0.05	0.05	0.05	-	0.10	0.10Zr
4032	11-13.5	1.0	0.5-1.3	-	0.8-1.3	0.10	0.5-1.3	0.25	-	-	-
5052	0.25	0.40	0.10	0.10	2.2-2.8	0.15-0.35	-	0.10	-	-	-
5083	0.40	0.40	0.10	0.4-1	4.0-4.9	0.05-0.25	-	0.25	-	0.15	-
5556	0.25	0.40	0.10	0.5-1	4.7-5.5	0.05-0.20	-	0.25	-	0.05-0.2	-
6061	0.4-0.8	0.7	0.15-0.4	0.15	0.8-1.2	0.04-0.35	-	0.25	-	0.15	-
7075	0.4	0.5	1.2-2	0.30	2.1-2.9	0.18-0.28	-	5.1-6.1	-	0.20	-
7178	0.4	0.5	1.6-2.4	0.30	2.4-3.1	0.18-0.35	-	6.3-7.3	-	0.20	-
7049A	0.4	0.5	1.2-1.9	0.50	2.1-3.1	0.05-0.25	-	7.2-8.4	-	0.25Zr + Ti	
8001	0.17	0.45-0.7	0.15	-	-	-	0.9-1.3	0.5	-	-	-
CASTING ALLOYS											
238.0	3.5-4.5	1.5	9.0-11	0.6	0.15-0.35	-	1.0	1.5	-	0.25	-
393.0	21.0-23.0	1.3	0.7-1.1	0.1	0.7-1.3	-	2.0-2.5	0.10	-	0.1-0.2	-
520.0	0.25	0.3	0.25	0.15	9.5-10.6	-	-	0.15	-	0.25	-
713.0	0.25	1.1	0.4-1	0.6	0.2-0.5	0.35	0.15	7.0-8.0	-	0.25	-
XC850.0	5.5-6.5	0.7	3.0-4.0	0.5	-	-	-	-	5.5-7	0.20	-

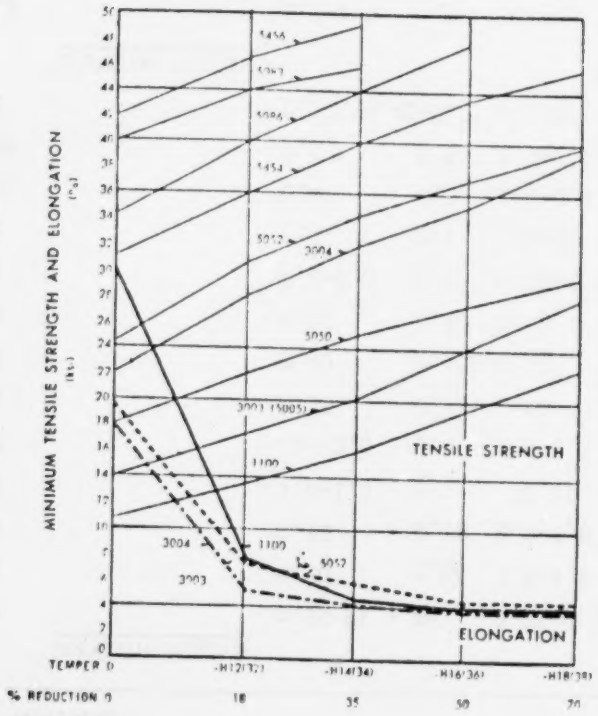


Fig. 7 STRAIN HARDENING CURVES OF SOME NON-HEAT-TREATABLE ALUMINIUM ALLOYS

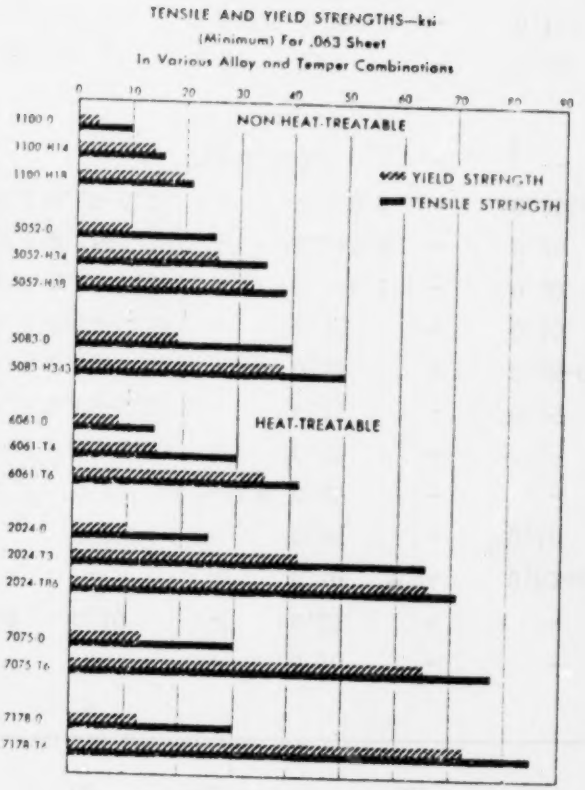


Fig. 8 MECHANICAL PROPERTIES OF REPRESENTATIVE ALUMINIUM ALLOYS

relatively broad tolerances in the standards regarding the analysis of the alloys give information only to a limited degree for the actual analysis, since with the scope of the permissible analysis for E-Al, which must have a minimum purity of 99,5% of aluminium, considerable variations in the properties can be achieved. Each impurity must be kept especially low, since some of them have a significant effect on the electrical conductivity of aluminium. Effect of some elements on the electrical resistance of aluminium is shown in the Table 8.

Table 8 EFFECT OF SOME ELEMENTS ON THE ELECTRICAL RESISTANCE IN BINARY SYSTEMS WITH ALUMINIUM (8)

Element added	dr/dC in 10^{-4} Ohm-mm^2/m	Element added	dr/dC in 10^{-4} Ohm-mm^2/m
Zr	454	Cu	31
Cr	421	B	13
V	333	Zn	10
Mn	307	Fe	9
Ti	259	Ni	5
Mg	56	Pb	2
Si	52	Sn	1

r= Electrical resistance

C= Concentration of the element in % by mass

It is possible to maintain in most cases the lower limit of the electrical conductivity of 61% IACS (International Annealed Copper Standard) in the hard drawn condition and at 62 or 63% in the soft annealed, especially when cast wire rod is used.

Depending on the application various degrees of hardness of wire are available. The electrical conductivity amounts to at least 62% IACS (36.0 Sm/mm^2) or 61% IACS (35.38Sm/mm^2). As a demonstration, typical values of the strength for two extreme conditions are

E-Al soft (O)	R 0,2	25 N/mm^2
	Rm	70 N/mm^2
	A10	50%
	A100	25%
E-Al superhard (H19)		
	R 0,2	205 $N.mm^2$
	Rm	220 N/mm^2
	A10	7%
	A100	1,5%

For certain applications, however, the strength of E-Al has proven to be insufficiant. To extend the above range of strength low-alloy electrical conductor alloys are developed by several companies. The main constituents and typical mechanical and electrical properties are given in the Table 9, (8). In this table the conventional AlMgSi and AlMg alloys are not included.

3.5 Technological properties of aluminium and aluminium alloys

Crystallization. The macrostructure of frozen aluminium and alloys is normal; the three layers (fine grain, columnar, coarse grain) are usually present depending on compositions and freezing conditions. As in the other metals, cellular growth is favored by very high temperature gradients and low impurity concentration. Thus, cellular growth can be found in some of the more drastically cooled zones of continuously cast aluminium and some alloys with samll solidification intervals.

Dendritic growth is the most common. Dendrites grow into a supercooled metal, with the rate of growth controlled by the heat removal rate, so that the temperature at the tip of the dendrite remain constant. The spacing between dendritic arms at the beginning of crystallization is very samll; but during the time that the melt is in the mushy state, coarsening takes place, by which many arms are reabsorbed. As a result the spacing is inversely proportional to the square root of the cooling rate.

Table 9 MECHANICAL AND ELECTRICAL PROPERTIES OF ELECTRICAL CONDACTOR ALLOYS (Key to Aluminium Alloys by W.Hufnagel, Aluminium Verlag, /Dusseldorf, 1982./

Alloy Tyupe	Designation	Manifacturer/ Country	Typical mechanical properties (Annealed at the drawing facility) Rm(MPa)	R 0,1(MPa)	A 250(%)	Donductivity % IACS
AlFe (Fe 0.75)	Triple-e	Southwire/USA	121	91	13	59.5
	A-4/1	Pechiney/F	123	98	10	59.6
	CK 74	Alcoa/USA	-	-	-	-
AlFeMg (0.7Fe;0.1Mg)	Ck 76	Alcoa/USA	145	112	14	59.5
	1320C	Alcan/UK	135	102	12	57.8
	A-4G/L	Pechiney/F	128	105	8	59.0
	XT	Eand E Kaye/GB	138	107	10.5	57.9
	Flexal*	Alunorf/D	-	-	-	-
AlCuMg (0.2 Cu 0.05Mg)	Ductalex**	Dlektrocoppar/S	119	91	19	60.3
	Super T/***	Southwire/USA	-	-	-	-
AlFeCu (0.6Fe 0.2Cu)	Stabiloy	Alusuisse/CH	145	108	11	59.8
		Olin/USA	-	-	-	-
	MS 122*	BICC/GB	-	-	-	-
AlFeSi (0.6Fe 0.1Si	Almhoflex*	Alumetal/I	-	-	-	-
	A - 4S/L*	Pechiney/F	-	-	-	-

* No comparable data given
** Be 0,01%
*** Co 1%

The coring that results during growth concentrates the lower-melting impurities between cells, dendritic arms or grains. So we have three types of microsegregations: cellular, dendritic and grain-boundary. When the compositional differences show long-range variation, for instance between the outside and inside of an ingot, this is considered as macrosegregation. Macrosegregations occur (a) prior to solidification: gravity, Ludwig-Soret, or (b) during solidification: normal, inverse, freckle, banding (12).

Grain size is controlled with the grain refining agents like the alloy Al Ti5Bl is in the industrial practice of aluminium founderies. Nowadays the castings of wrought alloys with uniform grain size over the full cross section it is obtained regularly.

Plastic deformation and formability. The ease with which aluminium may be fabricated into any form is one of the most important assets. Often it can compete successfully with cheaper materials having a lower degree of workability. The metal can be rolled to any desired thickness down to foil thinner than paper; aluminium sheet can be stamped, drawn, spun or roll-formed. It can be deep drawn. The metal also may be hammered or forged. Aluminium wire, drawn from rolled rod, may be stranded into cable of any desired size and type. There is almost no limit to the different shapes to which the metal may be extruded.

Plasticity in the hot working range is strongly affected by purity; aluminium with 0.8% iron plus silicon has a resistance to extrusion, for example, double that of Al 99,99%. Coarse or very fine grain size reduce resistance to deformation. Cold formability is reduced by silicon in solid solution, as a result of low Fe/Si ratios. However, the effect of other variables, such as tools, deformation rates, temperatures, alloys and especially texture, is predominant. The formability decreases and springback increases with increased hardness (7).

Heat treatment. The non-heat-treatable wrought alloys are usally designated in the 1XXX, 3XXX, 4XXX or 5XXX series. Alloys containing appreciable amounts of magnesium when supplied in strain hardened tempers are usually given a final elevated temperature treatment called stabilizing to insure stability of properties.

The heat-treatable alloys are those in the 2XXX, 6XXX or 7XXX series. The initial strength of alloys in this group is enhanced by the addition of alloying elements such as copper, magnesium, zinc and silicon. Since these elements singly or in various combinations show increase of solid solubility in aluminium with increasing temperature, it is possible to subject them to thermal treatments which will impart pronounced strengthening.

The first step, called heat treatment or solution heat treatment, is an elevated-temperature process designed to put the soluble element or elements in solid solution. This is followed by rapid quenching, usually in water, which momentarily "freezes" the structure and for a short time renders the alloy very workable. At room or elevated temperatures the alloys are not stable after quenching, however, precipitation of the constituents from the super-saturated solution begins. After a period of several days at room temperature, termed aging or room-temperature precipitation, the alloy is considerably stronger. By heating for a controlled time at slightly elevated temperatures, even further strengthening is possible and properties are stabilized. This process is called artificial aging or precipitation hardening.

By the proper combination of solution heat treatment, quenching, cold working and artificial aging, the higher strengths are obtained.

Recovery, recrystallization and grain growth. Cold working produces fragmentation of the original crystals into blocks, with an appreciable amount of dislocations between and inside the blocks. In recovery this highly unstable mosaic mover rapidly toward equilibrium the subgrains; the higher the recovery temperature the coarser the subgrains.

Whereas recovery is mainly a growth phenomenon, in the sense that the existing fragments remain mostly undisturbed, recrystallization requires the formation of a nucleus before it starts.

Recrystallization temperature depends on a variety of factors: time, percentage deformation, temperature of deformation, purity and grain size are the most important. The effect of alloying elements is different on

temperature of beginning or end of recrystallization, rate of recrystallization, and grain growth, etc. Interactions between various elements are also important.

Abnormal grain growth results when the amount of deformation is close to the critical Normal growth in which the range of grain sizes remains reasonably constant is favored by larger amounts of deformation, high annealing temperature and long annealing times.

Most alloying elements prevent or hinder both normal and abnormal grain growth in commercial alloys: elements that form samll, well-dispersed second phases are more effective than elements that are dissolved or present as few, coarse particles (7).

4. DEMANDS AS TO THE STANDARD OF PRODUCTS

The quality of semi-fabricated products is governed by standard specifications. The quality may be, meanwhile, defined or specified according:

1. International standards, e.g. ISO;
2. National general standards;
3. National standards concerning a limited group of special products;
5. Separate stipulations agreed upon by customers and semi manufacturers.

Standard limits for chemical composition, mechanical properties, physical properties and dimensional tolerances of wrought and cast products in general use are expressed, according to AA as follows (13).

Chemical composition - Standard limits are expressed to the following places:

Alloying elements and impurities

Less than 1/1000 percent	0.000X
1/1000-1/100 percent	0.00X
1/100-1/10 percent	0.0X

Unalloyed aluminium made by a
refining process ..... O.OXX
Alloys and unalloyed aluminium
not made by a refining process ..... O.OX
1/100 through 1/2 percent ..... O.XX
Over 1/2 percent ..... O.X; X.X;XX.X
Aluminium content of
unalloyed aluminium ..... XX.XX

The standard sequence for listing alloying element and impurities is as follows: Silicon, Iron, Copper; Manganese; Magnesium; Chromium; Nickel; Zinc; ...../; Titanium; Other Elements, Each; Other Elements; Total; Aluminium (Aluminium is specified as a minimum for unalloyed aluminium, and as a remainder for alluminium alloys. Additional elements having limits are inserted, in alphabetical order of their chemical symbols, between Zinc and Titanium, or are specified in notes.

Mechanical properties. Standard mechanical property limits are based on producer analysis of data accumulated from standard production material which has been sampled and tested using standard procedure. The limits are established after sufficient test data has been accumulated to adequately determine the form of the frequency distribution curve and to provide a reliable estimate of the population mean and standard deviation. In most instances the distribution is normal in form and properties are based on the results of the minimum of 100 tests from at least 10 different lots of material. In some instances, however, limits may be derived through their known relationship with another limit of property having sufficient data and meeting the above data base criteria. The standard mechanical property limits are subsequently established at levels at which 99 percent of the material is expected to conform at a confidence level of 0.95. Mechanical property limits are expected to meet those from the international and/or national standard for the same material, (alloy type) temper, product and/or technology of production.

As additional production experience is gained and additional test data becomes available, it may on occasion be necessary to revise a specific limit or more accurately reflect the capability of the process, materials and technology. In case of doubt as to the validity of a specific mechanical property limit, verification of its current status should be

obtained from (International Standard Institution).

Standard limits are expressed as follows:

Strength (ultimate, yield, etc.) ..... multiple of 5MPa

Exception: For a two-digit H temper whose second figure is odd, the standard limit for strength is the arithmetic mean, rounded to the nearest multiple of 5MPa of the standard limits for the adjacent two digit H tempers whose second digits are even.

Elongation in 50 mm or 5D ..... multiple of 1%
expressed as a whole number: D represents specimen diameter.

Exception: For certain products the elongation in the short transverse direction is expressed as a multiple of 0,5%
Elongation in 250 mm

Up thru 2.0 percent ..... multiple of 0.1%
Over 2.0 thru 3,0 percent ..... multiple of 0.2%
Over 3.0 thru 5.0 percent ..... multiple of 0.5%
Over 5.0 thru 10 percent ..... multiple of 1%
Over 10 thru 20 percent ..... multiple of 2%
Over 20 percent ..... multiple of 5 %

Over 5.0 percent elongation is expressed as a whole number.

Hardness, Brinell hardness number,
500 kgf load, 10mm ball ... multiple of 5 BHN, expressed as a whole number.

Physical properties. Standard limits are expressed to the following places:

Electrical conductivity, percent of IACS ..... XX.X

To determine applicable limiting values, when a value is specified to more decimal places than are used in the standards it shall be rounded off to the same number of places in conformity with rounding-off method of ASTM Recommended Practice E 29.

Chemical composition and specified properties. For purposes of determining conformity to the limits for chemical composition and properties, an observed value or a calculated value is rounded off

	Observed or calculated value is rounded off to
Chemical composition, Electrical conductivity Strength	nearest unit in last right-hand place or figures of specified limit
Elongation	
Longitudinal and/or long transverse specimens	
in 50 mm or 5D	- nearest multiple of 0.5%
in 250 mm	- nearest multiple of 0.1%
Short transverse specimens	
in 5D	- nearest multiple of 0.2 except when the use of 0.1 multiple will result in value coinciding with the specified minimum.
Brinell hardness	- nearest whole BHN converted from average diameter of indentation read to nearest multiple of 0.5 mm for routine acceptance tests and to nearest multiple of 0.02 mm for referee tests.

In addition to the above properties the Aluminium Association suggests additional methods and property analysis, like shear, stress, corrosion resistance and exfoliation corrosion resistance, as it is shown in Table 10. Then, the metalografic analysis are in some cases required for the specifications following the product delivery. At least it is necessary to control the macrostructure and microstructure at various stages of technology like casting, plastic deformation, thermal treatment with quenching, aging, annealing-recovery, recrystallization and grain growth) or surface treatment. Also, the deep drawing test and earing test is required for a certain application of strip or sheet: the bending test for a certain application of sheet, plate and bus bar; the formability test for a certain application of tube.

Table 10 TEST METHODS SUGGESTED BY THE ALUMINIUM ASSOCIATION (13)

Property	Test Methods
Chemical Analysis	ASTM Methods for Emission Spectrochemical Analysis, or ASTM E 34 Chemical Analysis of Aluminium and Aluminium Alloys. ASTM E 101 Spectrochemical Analysis of Aluminium and Aluminium Alloys by the Point-to Plane Technique. ASTM E 227 Optical Emission Spetrometric Analysis of Aluminium and Aluminium alloys by the Point-to-Plane Technique.
Tension	ASTM B 557M Tension Testing Wrought and Cast Aluminium and Magnesium Alloy Products. ASTM E 345 Methods for Tension Testing of Metallic Foil.
Hardness	ASTM F 10 Test for Brinell Hardness of Metallic Materials.
Shear	ASTM B 565 Shear Testing of Aluminium and Aluminium Alloy Rivets and Cold Heading Wire and Rods.
Electrical Conductivity or Resistivity*	ASTM B 342 Test for Electrical Conductivity by Use of Eddy Currents. ASTM B 193 Test fo Resistivity of Electrical Conductor Materials.
Stress Corrosion Resistance**	Fed. Std. No 151, Method 823 Stress Corrosion Test for Aluminium Alloy Plate Extrusions and Forgings by Alternate Immersion.

Table 10 continued

Property	Test Methods
Exfoliation Corrosion	ASTM 634 Test for Exfoliation Corrosion Susceptibility in 7000 Series Copper Containing Aluminium Alloys (EXCO test) Aluminium Association Method of Test for Visual Assessment of Exfolitation Corrosion Suscertibility of 5000 Series of Alloys-ASSET (Ammonium-salt-sodium exfoliation test) Method.

* B. 193 is used in case of dispute

** Stress Corrosion testing is normally applicable to thickness of 20.00 mm and over.

The quality standard for painted sheet covers minimum quality requirements and conformity tests for decorative and protective organic finishes on aluminium alloy sheet for exterior application. All lots of painted sheet are subjected to, and must pass production lot acceptance tests: natural weather exposure, accelerated weather exposure, salt spray resistance, humidity resistance, chemical resistance; and surface appearance, dry film hardness, color uniformity, dry film thickness, specular gloss, film adhesion, impact resistance and minimum bend radii.

The qualification and process control tests and inspections for quality control purposes are listed in Table 11. The tests for a wide range of product-mix are given. That is to say, some of the tests are applied for more or less all semi-manufactured products (as metallography for all semi-manufacturing processes)-"+", but some of them are for special application of products in the "category-"(+)".

Special attention in this paper will be concentrated on the tests which are to be carried out in the laboratories, either they are to be done for the product qualification or the process control. Some tests are usually done at or in the production line, like non-destructive tests, leak test and H_2 content test, and they will not be subject of detailed consideration, as the inspection (visual or dimensional) will not be too.

Oil and emulsion control laboratory will not be considered in this paper, too.

5. GENERAL INFORMATION ON QUALITY CONTROL

In his welcoming address the purchasing manager of a large company recently named three vital attributes for any supplier wishing to get and maintain successful business connections with the aluminium manufacturers over a prolonged period (14).

1. The supplier must provide the best quality called for by the specifications;

Table 11 QUALIFICATION AND PROCESS CONTROL TESTS AND INSPECTIONS FOR THE QUALITY CONTROL OF SEMI--FABRICATED PRODUCTS

Qualification (and process control) test	Category of semi - fabricated products				
	Rolled products	Extruded products	Wire and cable	Forgings	Castings
Chemical composition	+	+	+	+	+
Electrical conductivity	(+)	(+)	+	-	-
Strength (ultimate, yield, etc.)	+	+	+	+	+
Hardness	+	+	(+)	+	+
Elongation	+	+	+	+	+
Shear	-	(+)	(+)	-	-
Deep drawability and earing	(+)	-	-	-	-
Bending	(+)	(+)	(+)	-	-
Formality	(+)	(+)	-	-	-
Corrosion resistance	(+)	(+)	(+)	(+)	(+)
Metallography	+	+	+	+	+
Non-destructive tests - radiography - ultrasonic - eddy current	(+)	(+)	(+)	+	+
Leak test	-	(+)	-	-	-
H_2	-	-	-	-	+
Visual inspection - casting defects - metalworking defects - heat-treatment defects - corrosion	+	+	+	+	+
Dimensional inspection	+	+	+	+	+

2. he must strictly keep to delivery deadlines; and
3. he must offer the most favourable price acceptable to the purchaser

In order to meet such conditions we are required to obtain data on the quality of materials and products; the testing of it has been extensively conducted with the use of numbers of testing machines and instruments of various types.

In other words, material testing machines and instruments are expedient for determining the quality of materials; the data thus obtained concerning the quality of materials assures us of the designing the manufacture of products, both safe and economical.

Many of the material tests guaranteeing the required properties of existing materials are generally carried out according to the testing methods and the material testing machines and instruments as specified by the related national or international standards such as ASTM, DIN, BS, JIS, etc.

In view of the industrial rigid requirements today for the safety and economy of products, material testing machines and instruments have become all the more important in their ever-increasing applications such as rolling, extrusion, forging, casting, etc. of aluminium alloy, to cite only a few.

6. THE FUNCTIONS AND MAIN UNITS OF THE LABORATORIES FOR TESTING OF SEMI-FABRICATED PRODUCTS

Modern knowledge about metals, alloys and other metallurgical materials, and its extension or employment in research or industry, presupposes or requires:

(a) accurate chemical analysis whether by chemical methods which have a longer tradition but are continually developing, or by the newer physical methods;

(b) determination of structure, constitution and properties by physical methods.

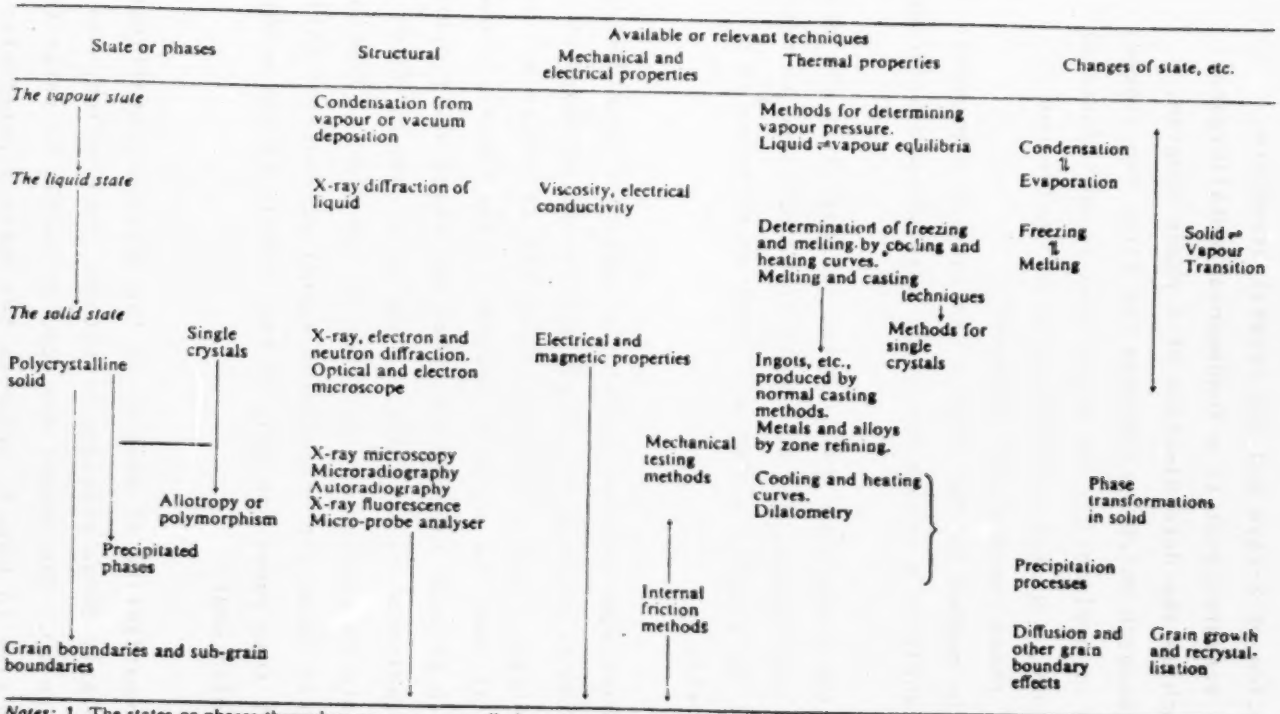
When considering a variety of application of physical methods, which are particularly relevant for Aluminium semi-fabricated Laboratories, four stages may be recognised (15).

1. The discovery of the basic physical phenomenon and its explanation, e.g. the diffraction of X-rays and the crystal structure.
2. Application as a research tool to a fundamental metallurgical investigation such as the determination of a phase diagram.
3. Application in research which presupposes the first two stages. This is the type of application one might find in an industrial research laboratory, e.g. the identification of inclusions or investigation of phase causing embrittlement.
4. Application of the method to the routine checking of a product either intermittently in a laboratory or by continuous monitoring.

It is essential for the practising metallurgist to appreciate the broad connection over the four stages, and obviously to be prepared to extend his knowledge beyond the present elementary level or to refer to a specialist in the field.

It is desirable to have some logical but simple basis for considering the techniques in relation to their material and the change of state of processes it may undergo. Such a basis is suggested in Figure 9. The point of this table is that the physical methods in the centre columns can be used either to provide information about the state and properties of the material as indicated on the left, or the processes by which it changes from one state to another as indicated on the right. Some of the methods - particularly those for determining vapour pressures - fall outside the scope of this paper and many of the techniques are mainly applicable to the solid state.

A more detailed schematization of several of the physical-metallurgical techniques, particularly those yielding structural information, can be provided as on Figure 10. The reader may find it useful to refer to those outlines from time to time in order to see where a particular technique fits in or relates to another This is particularly necessary



Notes: 1. The states or phases themselves are more generally investigated by the techniques in the 'structural' category but also by methods in the middle column.

2. The phase changes on the right are more generally investigated by the techniques in the adjacent column (thermal) and centre. In some cases, however, a structural technique can be used to follow changes of state.

Fig. 9 A BASIS FOR THE RELATION OF PHYSICAL TECHNIQUES TO A METAL AND ITS PHASE CHANGE (After K.W.Andrews)

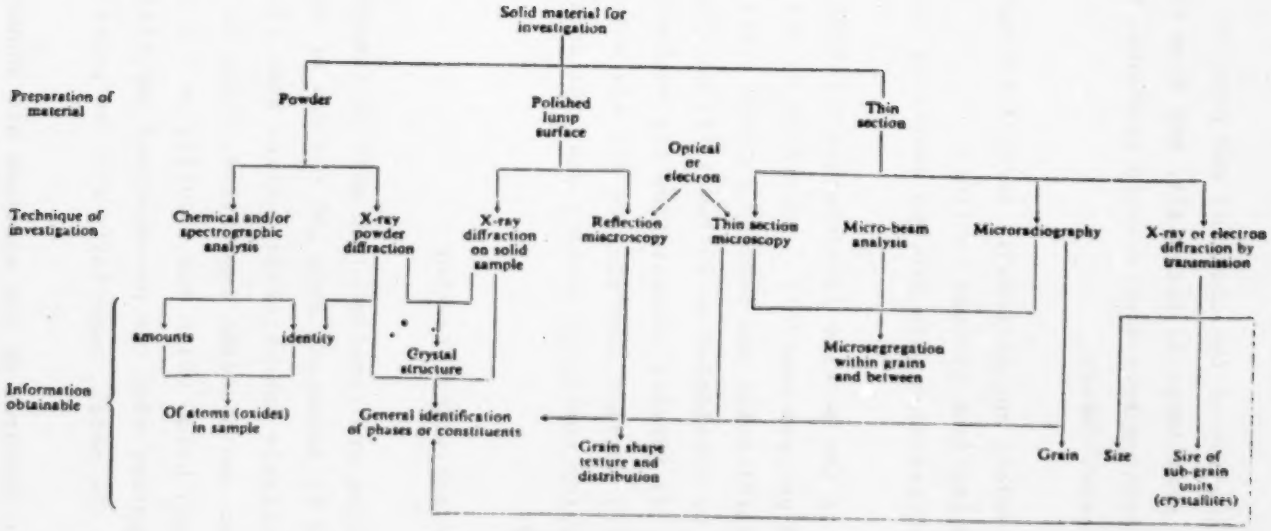


Fig. 10 PRINCIPAL PHYSICAL METHODS FOR DETERMINING STRUCTURE AND CONSTITUTION OF METALLURGICAL MATERIALS (After K.W.Andrews)

since, although all the techniques may not be available, the proper combination should always be sought or used when available.

From the variety of application of the chemical and physical methods in research and industry of metallurgical materials, and from the demands as to the standard of aluminium semi-manufactured products, two different levels may be established:

1. The most simple but modern and extendable service laboratories for semi-fabricated products (and process control).
2. Complete research laboratories with process modelling facilities.

The scope of this paper is the service laboratories for aluminium semi-fabricated products (and process control). According to the demands (see Section 4), and qualification and process control tests the main units of the laboratories may be considered as follows: (1) Service laboratories for analytical testing; (2) Service laboratories for mechanical and technological testing; (3) Service laboratories for electrical testing; (4) Service laboratories for corrosion testing and; (5) Service laboratories for metallography.

6.1 Service laboratories for analytical testing

When the grades of purities are considered it must be remembered that the purity is calculated by deducting from 100 the sum of the analysed impurities. Although reliable laboratories analyse some 15-25 elements which are the most common and abundant impurities, there is a lower limit (0,005% or 0,001% at best) below which the impurity is not reported. These minor amounts, together with the non-analysed impurities, may be sufficient to downgrade the metal, especially for the purer grades.

In Table 6 two important features of the analyses are shown: (a) the great variety of impurities that are present even in the purer metal and (b) the different proportions in the different products. In commercial aluminium the main impurities are iron and silicon with gallium, titanium,

vanadium, copper, sodium, manganese, nickel, and zinc present in different amounts, depending on the source of raw materials, technique, etc., but usually in amounts one order of magnitude lower than iron and silicon. In electrolytically refined aluminium, iron is still the main impurity, but the percentage of zinc, copper, magnesium and sodium may be very close to that of iron and exceed that of silicon. In zone refined aluminium another shift takes place; elements such as chromium, manganese, titanium and vanadium, which in refining are removed very slowly or tend to concentrate in the refined product, become the dominant impurities.

Although iron, silicon, gallium, titanium, vanadium, copper, sodium, manganese, nickel and zinc are present in commercial aluminium as a main impurity, because of their influence on electrical conductivity, chromium and zirconium have to be analysed too. Let us take 50 ppm as a limit, but still we must have in mind that standard specifications for chemical composition are based on knowledge about influence of certain element on the properties important in fabrication and application, and about technological possibilities and cost for their removal. Anywhere, every concrete situation has to be considered individually, depending on the product-mix.

Having in mind the main alloying element limits, (see Table 7) standards, the amount and importance of the impurities in commercial (secondary and E-Al aluminium may be given one rather wide program for the chemical laboratorary for semi-fabricated products of a wide structure, according to the elements to be analysed and their concentration range (Table 12).

We have to keep in mind particular products such as refined and zone refined aluminium, or aluminium alloys based on them; then recent aluminium-litium alloys, or other rather special materials in aluminium semi-manufacturing industry.

As suggested by the Aluminium Association and used by the most aluminium semi-manufacturing plants, the optical emission (or X-ray) spectrometry is the most suitable for determination of alloying elements and impurities in commercially pure aluminium and aluminium alloys. Computer

Table 12 THE LIST OF ELEMENTS WITH THEIR CONCENTRATIONS TO BE ANALYSED IN THE CHEMICAL (DEPARTMENT OF THE) LABORATORIES FOR ALUMINIUM SEMI-FABRICATED PRODUCTS

Elements to be analysed		Concentration range, % - upper limit*	
		As alloying addition**	As impurity
1		2	3
Ag		0.5	-
B		0.1	-
Be		0.1	-
Bi		0.1	-
Cr		1.0	0.1
cu	(wrougth)	7.0	0.1
	(casting)	11.0	0.5
Fe		1.5	1.5
Ga		-	0.1
Mg	(wrougth)	6.0	0.1
	(casting)	11.0	-
Mn		2.0	0.1
Na		-	0.1
Ni		1.0	-
Pb		1.0	-
Si	(wrougth)	13.5	0.5
	(casting)	23.0	0.5
Sn		22.0	-
Ti		0.5	0.1
V		-	0,1
Zn	(wrougth)	9.0	0.5
	(casting)	8.0	0.5
Zr		0.5	0.1

* Upper limits to be able to analyse, what is little bit higher than the expected conncentrations.

** Micro-alloying, refining and grain-refining additions too.

controlled optical emission spectrometer system may be specifically designed for routine analysis of aluminium and its alloys. It is particularly suitable for foundries and all kinds of secondary producers - but will also meet the needs for material checking in any phases of the semi-manufacturing process. It permits rapid, simultaneous analysis of up to 20 elements in the simpliest version. The system incorporates special features to optimise analysis for both mayor alloying elements and impurities or trace constituents. Advanced electronics enable wide ranges of concentrations to be determined - and a powerful microcomputer eliminates the need for tedious manual calculations.

The technique of optical emission spectrometry is based on the fact that then the material is vaporised by an electrical discharge, its component atoms becomes excited and their electrons move to higher energy levels. In returning to their normal state, these electrons release the energy they had acquired, in the form of lignt. Each element in the material produces a characteristic light emission comprising a number of discrete wave lengths. These can be separated and focused using a concave diffraction grating to produce a line spectrum. Quantitative determination of an element is possible by measuring the intensity of a selected line. The computer uses strong calibration data, derived from standard samples of known composition, to conveet intensities into element concentrations. Basic principles of the optical emission spectrometry is shown on Fig. 11.

The main equipment units of the laboratories for analytical testing are:

Testing instrument

- Optical emission Spectrometer with accessories (for elements selected in close collaboration with equipment producer experts - because of the fact that sensitivity and detection range for impurities and alloying elements respectively may need two lines for two concentration ranges of the same element - one for the impurity range and another for the alloy range; in some cases one line is enough).
- Set of calibration standards

Sample preparation equipment

- Surface grinding machine with accessories
- Melting and centrifugal casting machine

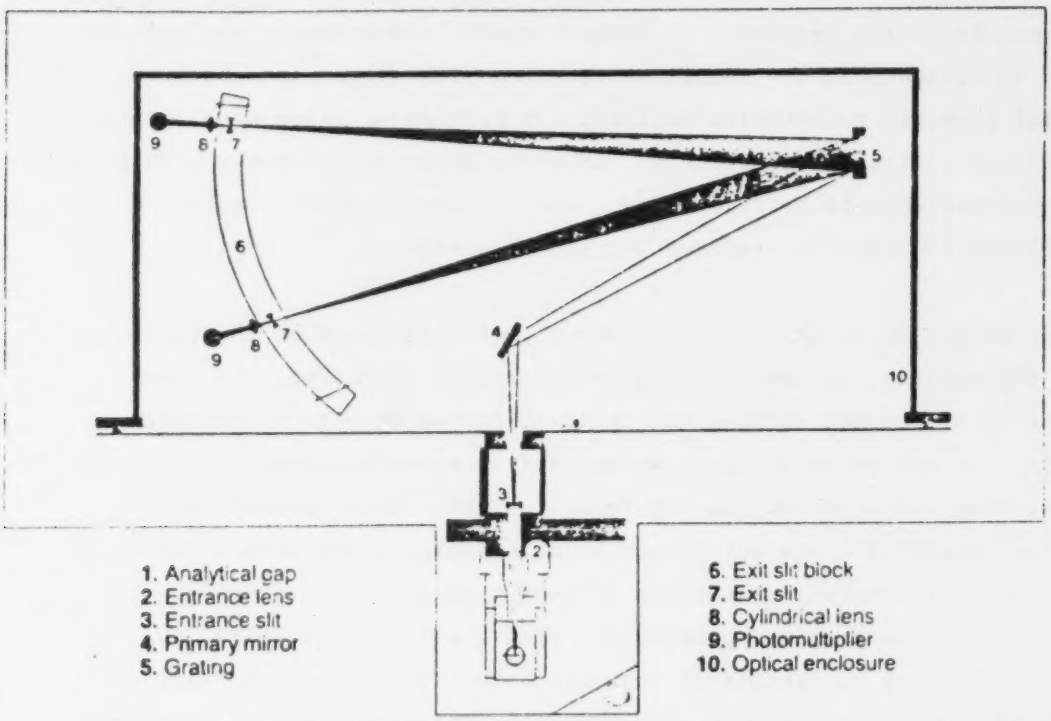


Fig. 11 BASIC PRINCIPLES OF THE OPTICAL EMISSION SPECTROMETRY

Extension of the laboratories with the inductively coupled plasma system (ICP) or the atomic absorption spectrometry (AAS) for high precision low concentration trace elements is possible. Of course, other methods may be used if appropriate.

ICP, as an attachment of optical emission specrometer, gives low spectral background and linear response over a vide dynamic range of concentrations - allowing determinations from trace levels to major constituents. A high temperature plasma is obtained by inductively energising an argon flow using a radio-frequency generator. Samples are first nebulished by means

of a adjusted cross-flow nebuliser, and the resulting argon-borne aerosol is introduced axially into the plasma.

6.2 Service laboratories for mechanical and technological testing

The mechanical properties normally obtained from tension of test specimen, and the methods used, are yield strength, ultimate or tensile strength and elongation, as follows:

YIELD STRENGTH (0.2% offset). Yield strength is determined by either the "offset method" or the "extension under load method", except that the former is more accurate and is used in case of dispute.

Yield strength by the "offset method" is computed from a load-strain curve obtained by means of an extensometer. A straight line is drawn parallel to the initial straight line portion of the load-strain curve and at a distance to the right corresponding to 0.2 percent offset (0.002 mm per mm of gauge length). The load reached at the point where this straight line intersects the curve divided by the original cross-sectional area (mm^2) of the tension test specimen is the yield strength.

Yield strength by the "extension under load method" is the load reached at the extension under load (X) computed by the following formula divided by the original cross-sectional area of the tension test specimen: X=Y/E + specified offset, where: X= extension under load (mm per mm of gauge length), Y= specified yield strength (MPa), E= nominal modulus of elasticity (Youngs modulus) of the material (MPa), specified offset (0.2%)= 0.002 mm per mm of gauge length.

Ultimate or tensile strength. Ultimate strength is determined by dividing the maximum load carried by the specimen during a tension test by the original cross-sectional area of the specimen.

Elongation. After completion of the tension test, the ends of the fractured specimen are fitted together carefully and the distance between the gauge marks measured to the nearest 0.25 mm. A percentage scale reading to 0.5 percent of a gauge length may be used. The elongation is the increase in gauge length, expressed as a percentage of the original gauge length.

Universal electro-mechanical testing machines are high performance testing machines for measuring strength and mechanical and technological properties of metals. The constant rate strain loading by the electro-mechanical drive system and automatic recording of both loan and elongation in addition to the excellent maneuverability make them suited for various applications, especially quality control. The load weighing system have to confirm to all popular standards including ISO, ASTM, DIN, DS, JIS and AFNOR.

On request, the universal testing machines by many suppliers can be delivered with various test devices, as follows:

Compression test device for a metal specimen; compression test of a cylindrical specimen.

Bending test device for a metal specimen; third point loading, central point loading, guided bend test.

Shear test device; the load required to shear a metal specimen with a ring cutter is measured.

Deep drawability test device (of cylindrical or conical die type); deep drawability test of ductile sheet or plate material by pressing specimen into a bottomed cylindrical or conical cup form with a punch and a conical die.

Tube expansion test device; inner pressure rupture test of tube, suitable for special tublar specimen used in instruments; inner pressure is applied by fitting soft metal in the specimen and applying an axial load; diameter displacement of specimen is measured by differential transformers in 3-point average value system.

Brinell hardness test device; installed between the lowest crosshead and the table, to perform Brinell hardness test by compressing a steel ball on specimen with a constant load.

Of course, instead of these attachable test devices it is very recommendable to have separate specialized instruments, especially for deep drawability (and earing), to-and-fro bending, and Brinell hardness. That, certainly, depends on the character of production and (semi-fabricated) product-mix.

It is to be mentioned that with the universal testing machines devices for tests in desired environments are available too: thermostatic test device, high temperature test device, super low test device, thermo-hydrostatic test device, immersion test device, corrosion stress test device etc.

Programable calculation and control system enables testing machines to be converted to a completely automatic test and data handling system. Application programs to suit more general material test are available. Usual tension test program provide measurements of the following parameters (see also diagram fig. 12):

- Elastic modulus;
- Up to three proof stress values;
- Upper yield stress point;
- Stress and strain at peak load;
- Total, elastic and plastic strain, etc.

Statistics are available on demand on any time during the series of tests and are:

- Number of tests conducted;
- Number of valid tests;
- Mean values of results for series of tests;
- Standard deviations for results of series of tests;
- Coefficients of variation;
- Maximum and minimum values for series of tests, etc.

Similar data are available with programable calculation and control system from other tests. It is possible to get, by accessories and data processing

system, more sofisticated data like true stress true strain curves, plastic strain ratio, namely "n" and "r" parameters.

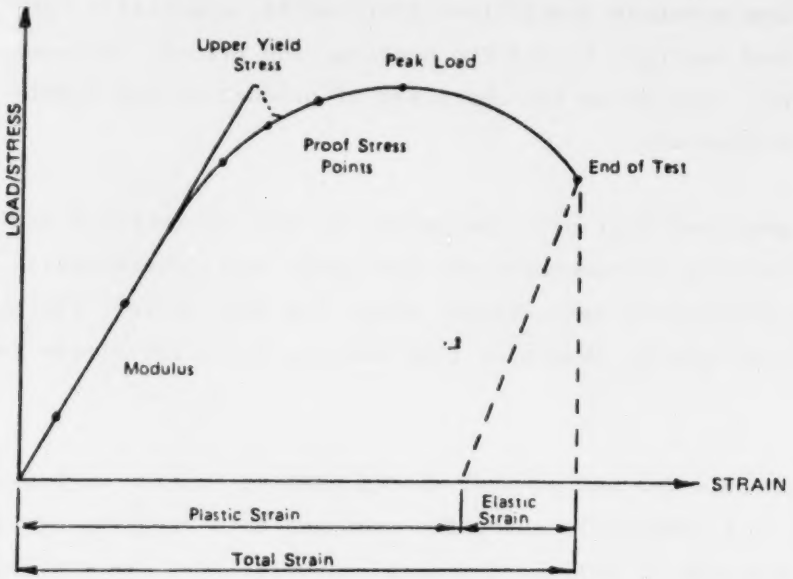


Fig. 12 CHARACTERISTIC POINTS AND PROPERTIES ON THE LOAD/STRESS - STRAIN CURVE OF METALS

To meet a facility for qualification and process control tests (see Table 11) in the scope of mechanical and technological testing the main equipment units suggested here are:

Testing instruments

- Universal testing machine with accessories, max. load capacity 100 kN;
- Universal testing machine with accessories, max. load capacity 5 kN (for foil testing);
- Brinell hardness tester;
- To-and-fro bend tester;
- Erixen sheet metal testing machine, for deep drawing and earing.

Sample preparation equipment

Universal aluminium machining equipment for cutting, turning, milling and drilling.

Recent years have seen a rapid improvement in the techniques to study the behaviour of materials and products in the process of fatigue and under vibrational load. There is now a strong demand for a material testing machine that uses a closed loop system to provide any type of load waves. They are best suited for research and quality control in various fields of aircrafts, automobiles, ships, civil engineering, building, etc. Extension of the laboratories with the electro-hydraulic fatigue testing machine that have a closed loop system seems probable, if it will be suitable according to production program.

6.3 Service laboratories for electrical testing

Electrical conductor property limits are for aluminium generally described in sections 3 and 4 of this study. It is easy to see that we have to measure the electrical conductivity from about 62 IACS (or equivalent volume resistivity of 0.027808 ohn. mm^2/m, or equivalent mass resistivity of 0.075221 ohn. gr/m) to down, depending mostly on the temper, metal purity and alloy type.

Standard precision Wheatstone (and Kelvin) DC resistance bridge is a single instrument that is applied in aluminium and conductor industry. It meets requirements of high accuracy, extremely-low or very-high resistance values, remote measurements and portability. Total measuring range is usually from 1 micro-ohm to T-ohm in 7 ranges; six digits or 1,111,110 counts resolution; 0.01% accuracy, direct reading; sensitivity (with internal source - -6V set of 4D cells: 2 micro ohm at very low values (10 ppm at 1 ohm).

6.4 Service laboratories for corrosion testing

Prior to their use, specific basic paint formulations or anodization treatments are subjected to qualifying tests. Customary colors formulated similarly to the basic formulations for delivery within a few weeks cannot be subjected to long-term testing prior to use. However, if failure is noted when they are subsequently tested, such customary colors are either discontinued or reformulated for improved performance. All lots of

painted sheet are subjected to, and must pass production lot acceptance tests (surface appearance, dry film hardness, color uniformity, dry film thickness, specular gloss, film adhesion, impact resistance, and recommended minimum bend radii).

Corrosion qualification tests and test method are as follows (13):

Natural weather exposure. No checking, crazing or adhesion loss, and only slight-to-moderate chalking (No. 6 degree of ASTM Designation: D659) and slight fading or color change of specimen when exposured one year outdoor at 45° angle facing south.

Accelerated weather-exposure. No adhesion loss only slight chalking and fading or color change, plus normal water staining when tested 500 hours in accordance with Method 6151 of Federal Test Method 141 using type E apparatus described in ASTM Designation: G 23. Following exposure, examine film visually in adequately lighted area for conformance to requirement.

Salt spray resistance. Undercutting of film from scored line, 1.5 mm maximum when tested 1000 hours in accordance with Method 6061 of Federal Test Method 141 or ASTM Designation: B 117 using 5 percent sodium chloride solution. Film scored diagonally sufficiently deep to expose base metal and edges exposed.

Humidity resistance. No loss of adhesion or gloss and no color change or staining when tested totally immersed separate samples in mineral spirits, 2.0 percent trisolium phosphate solution and 2.0 percent soap solution for 24 hours at room temperature (25°C). Also immerse separate sample for 72 hours in a 3 percent detergent solution maintained at 38°C.

The main equipment units of the laboratories for corrosion testing are:

- Corrosion diagnostic system (cabinet), operated according to the Federal Test Method 141 (USA) - methods 6061, 6151 and 6201;

- Apparatus for measuring coating thickness;
- Other small instruments and laboratory glasses.

The proper selection of materials is frequently influenced by their corrosion characteristics and corrosion resistance. Corrosion phenomena are basically electrochemical in nature and electrochemistry provides a powerful tool for rapidly and accurately determining both corrosion rates and corrosion mechanisms. The most popular and frequently used electrochemical technique in this field is the Corrosion measurement system. With this system the following experiments can be conducted: (1) automatic potentiodynamic anodic polarization plots, (2) polarization resistance, (3) Tafel plots, (4) corrosion potentials, (5) galvanic corrosion and other techniques such as cyclic polarisation, chrondampermetry, and constant current electrolysis can be conducted to assist in characterizing electrode materials and evaluating corrosion behaviour.

So, extension of the service laboratories for corrosion testing with Corrosion measurement system seems to be anticipated after a certain experience.

6.5 Service laboratories for metallography

It is well known that the properties of aluminium and aluminium alloys depend on the macrostructure and microstructure. Consequently, attention must be given to:

1) the structure obtained after solidification;
2) the structure obtained after homogenisation;
3) the structure obtained after plastic deformation (by rolling, extrusion, forging, drawing, deep drawing);
4) the structure obtained after recrystallization or partial annealing;
5) the structure obtained after solution heat treatment and quenching from state (3);
6) the structure obtained after aging from state (5).

It will now be obvious that the properties depend greatly on the initial condition, i.e. on the as-cast state (following solidification). This in turn is a function of (a) molten state and the various treatments to which the melt has been subjected (inocculation, degasification) and (b) method and casting conditions.

So, all the mentioned processes have to be followed with metallography if we want to keep a full control of processes and material properties. That will assure the product quality.

With metallography we observe macrostructure, grain size grain shape, and distribution cell size and shape, segregations, intermetalics, non-metalics, gas porosity, grain boundries, sub-grains, sub-boundries, grain orientation, metal flow direction, deformation bends and lines, nucleation, recrystallization, grain growth, precipitations, etc.

Light (or optical) microscopy is used in most service laboratories for metallography at the aluminium semi-manufacturing plants. It is very suitable for the characterization of macrostructure and microstructure. To do this the main equipment units are necessary, as follows:

Testing instruments

- Stereomicroscope with camera, for observation and registration of macrostructure;
- Incident light (polarization) microscope with camera, for the investigation, observation and registration of microstructure;
- Foto-laboratory, complete.

Sample preparation equipment

- Cutting machine;
- Mounting press;
- Grinding machine;
- Polishing machine;
- Electro-polishing machine;
- Trans-pol-machine for metallographic replica

As the light microscopy is used for observation and analysis of (micro) structure, the advanced and finer results and data can be obtained:

1) with the system for quantitative metallography, fully automated and computerized;
2) with scanning electron microscopy with energy dispersive spectrometer;
3) with electron microprobe analyser;
4) with transmission electron microscope

In this direction the extension of laboratories for metallography can be realised.

Adding to that an X-Ray diffractometer for phase and texture analysis we would get, with all extensions, a real research laboratories for metal-Physics, but still without process modelling facilities.

7. SELECTION OF THE TESTING METHODS AND EQUIPMENT FOR SETTING UP TESTING LABORATORIES FOR SEMI-FABRICATED PRODUCTS

The demands as to the standard of semi-fabricated products and process control were discussed in chapter 4. The main units of the laboratories with their activities and equipment were analysed in chapter 6. Testing methods were subject of chapters 4 and 6. Summary of these is Table 13 in which the testing methods and equipment (with some possible supplier firms and prices) of laboratories for aluminium semi-fabricated products are listed.

8. REQUIREMENTS FOR UTILITIES AND BUILDING

It should be mentioned here that a modern laboratory of any level requires basic infrastructure: water supply, electricity, canalization, climatization and gas supply, likely compressed air. If the first three are missing no laboratory can be operated. The latter can be substituted somehow by special facilities.

In Table 14 particular requirements for utilities and building are shown.

According to the requirements, the limited capacity of the financial sources and a usually gradual development of semi-manufacturing industry it is reasonable to establish the laboratory step by step using the "building block" principle.

An example of a very flexible outlay allowing stepwise enlargement of the laboratory from the simplest type to higher level is shown on Figure 13.

Table 13

TESTING METHODS AND EQUIPMENT OF LABORATORIES
FOR ALUMINIUM SEMI-FABRICATED PRODUCTS

Kind of testing	Testing methods	Equipment	Supplier firm	1984 Price, US $
1	2	3	4	5
Analytical testing	Optical emission spectrometric analysis of aluminium and aluminium alloys by the point-to-pane technique (ASTM E227)	Simultaneous optical emission spectrometer	Applied Research Laboratories sa, 1024 Ecublens Switzerland	120,000
			Philips Nederland B.V. 5600 PB Eindhoven Nederland	
Sample preparation equipment		Surface grinding machine	It is usually offered by supplier of spectrometer	6,000
		Melting and centrifugal casting machine	"	15,000
Mechanical and technological testing	Tension testing wrought and cast aluminium and magnesium alloy procoucts (ASTM : B 557M)	Universal testing machine, 100 kN - with accessories	Instron Ltd. High Wycombe, Buck HP 125Y Great Britan	80,000
			Shimadzu Corporation Tokio 160, Japan	
	Methods for tension testing of metallic foil (ASTM E 345)	Universal testing machine, 5 kN	Zwick GmbH 7900 Ulm, West Germany	40,000
			Amsler Otto Wolpert-Werke 6700 Ludwigshafen	
	Test for brinell hardness of materials (ASTM E 10)	Brinell hardness tester	West Germany	6,000

1	2	3	4	5
		Erixen sheet metal testing machine	HILLE Engineering Ltd. Sheffield S3 8DL England Erichsen GMBH, 5870 Hemer-Sundwig/Westf. West Germany	40,000
		To-end-fro bend tester	Amsler Otto Wolpert-Werke GMBH 6700 Ludwigshafen West Germany	3,000
Sample preparation equipment		Universal and standard (aluminium) machining equipment for cutting, turning, milling, drilling		20,000
Electrical testing	Test for resistivity of electrical conductor materials (ASTM B 193)	Wheastone DC resistance bridge	FLUKE, Yokogava Electric Works, LTD., Tokyo, Japan	2,000
Corrosion testing	Federal (USA) Test Method 141 - Methods 6061 6151 and 6201	Corrosion diagnostic system (cabinet)	Liebisch, 4800 Bielefeld West Germany Brabender, 4130 Moers West Germany	20,000
		Apparatus for measuring coating thickness	UPA Technology, Inc. 60 Oak Drive Syosset, N.Y. 11791, USA	1,500
		Other small instruments and laboratory glasses		5,000

1	2	3	4	5
Metallography	see (16) Metals Handbook, METALLOGRAPHY STRUCTURES AND PHASE DIAGRAMS, Vol. 8, ASM, Metals Park, Ohio, 1973.	Stereomicroscope, with accessories	OPTON, Opton Feintechnik GmbH, 7082-Oberkochen West Germany	
		Incident light polarization microscope, with accessories	ZEISS, Carl Zeiss, 7080-Oberkochen West Germany	40,000
			OLIMPUS, Olimpus Optical Co. (Europa) 2000-Hamburg West Germany	
			REICHERT, C.Reichert Optische werke, 1171 - Wien, Austria	
			BUEHLER, Apparatus for microstructural analysis, Illionis USA 60044	
Sample preparation equipment		Cutting machine	STRUERS, Chopenhagen Denmark	5,000
		Mounting press		4,000
		Grinding machine		1,500
		Polishing machine		2,000
		Electro-polishing machine trans-pol--machine, for metallographic replica		5,000
				1,500
		Foto-laboratory, complete		5,000

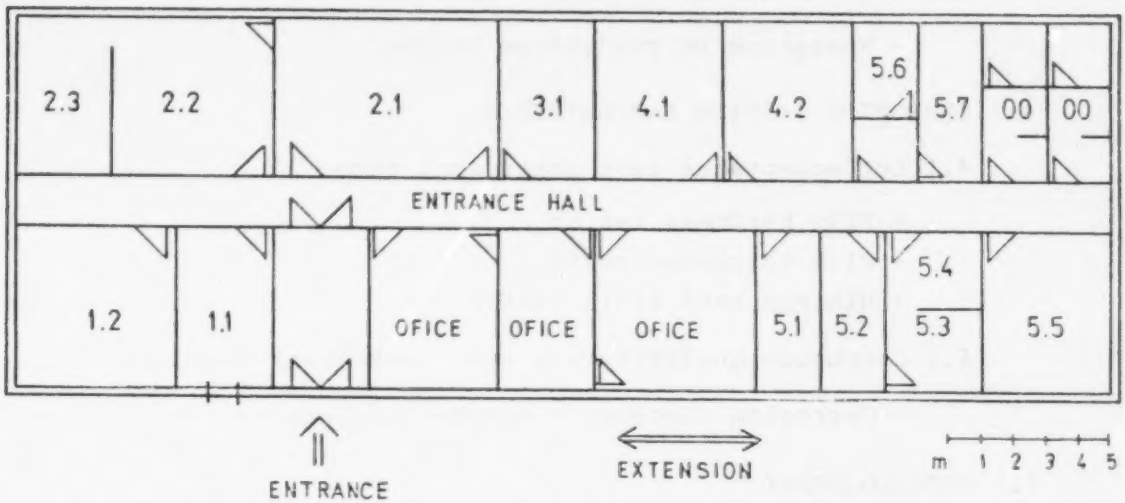
Table 14. PARTICULAR REQUIREMENTS FOR UTILITIES AND BUILDING

Laboratory/room Purpose	Requirements					
	Electrical, Voltage	Environmental, Operation temperature	Water	Gas	Others	Space, min. m^2
1	2	3	4	5	6	7
1. ANALYTICAL TESTING LABORATORIES						
1.1 Sample preparation room	220 V	-	(+)	Air, 6 bar	-	10
1.2 Analytical testing; instrument room	220 V	18-28°C	(+)	Argon 99,995%	Rel.hum. les than 65%	15
2. MECHANICAL AND TECHNOLOGICAL						
2.1 Sample preparation room	220 V	-	(+)	Air, 6 bar	-	30
2.2 Tensile testing; instrument room	220 V	-	(+)	-	-	20
2.3 Technological testing; instrument room	220 V	-	(+)	-	-	15
3. ELECTRICAL TESTING LABORATORIES						
3.1 Measuring instruments room	220 V	15-25°C	(+)	-	-	10

1	2	3	4	5	6	7
4. CORROSION TESTING LABORATORIES						
4.1 Lot acceptance test; instruments room	220 V	-	+	-	-	10
4.2 Corrosion qualification test; instruments room	220 V	-	+	Air 6 bar	-	15
5. METALLOGRAPHY						
5.1 Macroeaching and microeaching room	220 V	-	+	-	-	10
5.2 Sample preparation room	220 V	-	+	-	-	10
5.3 Sample preparation room	220 V	-	+	-	-	5
5.4 Sample preparation room	220 V	-	+	-	-	5
5.5 Microstructure observation; instrument room	220 V	-	(+)	-	-	15
5.6 Foto laboratory room	220 V	-	+	-	-	5
5.7 Foto laboratory room	220 V	-	(+)	-	-	5

(+) not necessary as a technological demand, but recommendable for common use.

Fig. 13 SUGGESTED LAYOUT OF LABORATORY FOR SEMI-MANUFACTURED PRODUCTS



1. ANALYTICAL TESTING LABORATORIES

1.1 Sample preparation room
- Surface grinding machine
- Melting and centrifugal casting machine

1.2 Analytical testing room
- Optical emission spectrometer

2. MECHANICAL AND TECHNOLOGICAL TESTING LABORATORIES

2.1 Sample preparation room
- Cutting machine
- Turning machine
- Milling machine
- Drilling machine

2.2 Tensile testing instrument room
- Universal testing machine 100 kN
- Universal testing machine 5 kN

2.3 Technological testing instrument room
- Erixen sheet metal testing machines
- To-and-fro bend tester
- Hardness tester

3. ELECTRICAL TESTING LABORATORIES

3.1 Measuring instrument room

- Wheastone DC resistance bridge

4. CORROSION TESTING LABORATORIES

4.1 Lot acceptance test instrument room

- Film hardness tester
- Film thickness tester
- Minimum bend radii tester

4.2 Corrosion qualification test instrument room

- Corrosion diagnostic system (cabinet)

5. METALLOGRAPHY

5.1 Macro etching and micro etching room

- Digestor/Exhauster

5.2 Sample preparation room

- Cutting machine
- Mounting press

5.3 Sample preparation room

- Grinding machine
- Polishing machine

5.4 Sample preparation room

- Electro polishing instrument

5.5 Microstructure observation room

- Stereomicroscope
- Incident light polarization microscope

5.6 Foto laboratory room

- Dark room

5.7 Foto laboratory room

- Film drying cabinet
- Foto drying machine

9. HUMAN RESOURCES AND TRAINING REQUIREMENTS

Organization scheme for a complex of laboratories for aluminium semi-manufactured products is shown in Figure 14. It is presupposed that analytical laboratories have to work 3 shifts (24 hours every day) while others 1 shift (8 hours per working day, excluding Saturday and Sunday).

Supposing that the specialists (including management) selected for the laboratories for aluminium semi-manufactured products have graduated, but have no experience in organizing and operating such kind of laboratory, special training would be required.

Two kinds of training might be proposed:

- a general review course and laboratory practices on analytical, mechanical, technological, corrosion, electrical and metallographical examinations for the evaluation of different kinds of materials, tempers and semi-fabricated products;

- special courses in particular investigation technique according to the main activities and the equipment accessible.

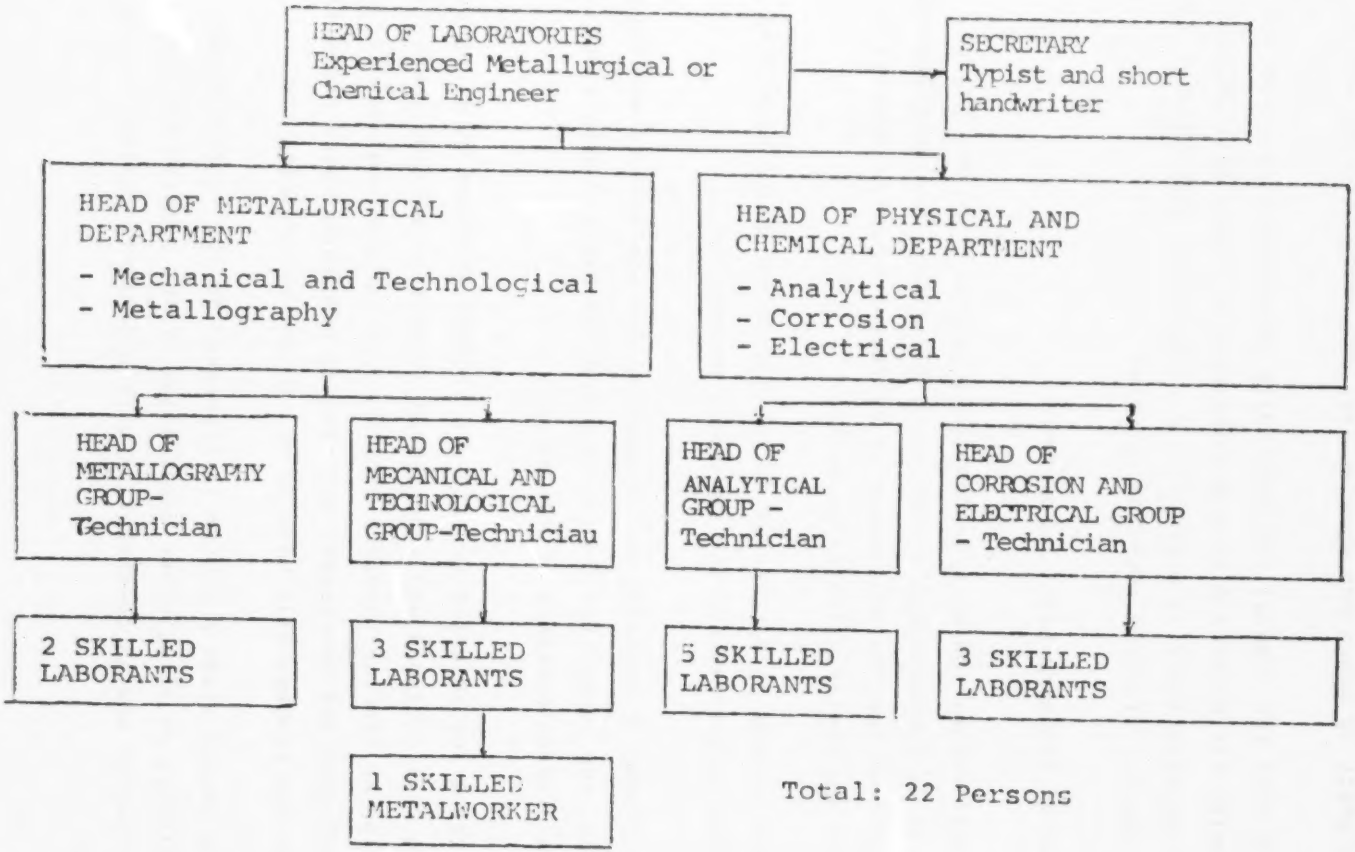
The first kind of training is recommended for specialists who have graduated, the second for technicians and laborants. Both kinds of training program consists of two stages:

- at first a few selected experts are trained (in form of group training) in the well equipped and experienced laboratory serving specialized but also as wide as possible programme of various semi-manufacturing technologies and processes, and various semi-fabricated products. The production process will have to be subject of training too.

- in the second stage a course is organised in the installed new laboratory, on site, under supervision of the experts invited for the installation and in co-operation with scientists trained in the first stage.

Fig. 14

PROPOSED
ORGANIZATION SHEME OF LABORATORIES FOR
ALUMINIUM SEMI-MANUFACTURED PRODUCTS



Total: 22 Persons

10. RECOMMENDATIONS

Whilst it is understood that the individual semi-manufacturing aluminium plants in a given country have - in accordance with their product-mix - their own more or less modern testing facilities for process and quality control, the establishment of a central laboratory for aluminium semi-fabricated products with sophisticated and modern laboratory equipment is highly recommended, particularly in a country which produces a variety of aluminium semi-fabricates. Such a laboratory would also act as research and development centre for the local industry e.g. advanced research and technology development for new materials and products to be introduced in the market. In addition, trouble shooting consultancy work may be provided, such as various test work to confirm or revise previous findings by the aluminium semi-manufacturing plants. The laboratory should be designed in such a way so as to allow expansion, as need may be, to grow into a full-fledged research institute for the aluminium industry.

The Aluminium Institute for Research and Development in Titograd has received and is receiving technical assistance from UNIDO, e.g. in the provision of sophisticated equipment such as scanning electron microscope and elaboration of R and D programmes ranging from investigation of bauxite and alumina up to development of aluminium semi-finished products. Within this project new research methods have been developed particularly with regard to metallography and casting technology for aluminium alloys, phase identification and texture research by x-ray diffraction, technological treatment and product quality of aluminium alloys, and many more. Also, the Institute is providing useful testing and consultancy work to the local aluminium semi-manufacturers in the area. The latter comprises aluminium rolling mill, extrusion plant, wire and cable production and a forge. A foundry plant is under establishment and will also need to be served, so that practically all categories of semi-manufacturing aluminium plants are covered. This paper may be used as a guide to establish the work programme and structure of testing

laboratories for semi-fabricated products in a given developing country. A detailed project design for a laboratory would have to be prepared by a consulting organization, according to the requirements and product-mix of the semi-manufacturing plant. Preferably, all activities connected with the setting up of the laboratory should be performed by the same organization.

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